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Two identical tests were performed on half scale P-2 model earth penetrators to define strains and accelerations imparted during high velocity impact, 1800 ft/s, into a sandstone media. Tests were conducted in the reverse ballistic mode by firing the sandstone at the P-2 test models. Extensive strain and acceleration data was recorded during the successful performance of these tests. Both P-2 models were reviewed after testing and all test objectives were achieved.

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20. ABSTRACT (Continued)

A brief description of the test facility, instrumentation and procedures is presented.

The test results are presented and discussed.

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PREFACE

This final report documents the procedures employed and the results obtained in performing two reverse ballistic tests on half scale P-2 earth penetrator models. These tests were performed to measure strain and acceleration levels on half scale P-2 earth penetrator models for 1800 ft/s impact with sandstone media. The two tests were identical to determine if dynamic impact data of the type obtained was repeatable from test to test. Good data was obtained on 95 percent of the strain gage channels and 60 percent of the accelerometer channels for both tests. The data was highly repeatable and agreed well with pretest predictions. The test results further verified the reverse ballistic test technique and provided confidence that the structural response of earth penetrators to high velocity impacts can be predicted and measured.

The program was conducted by Avco Systems Division under Charge Order P00001 to Contract DNA001-C-75-0181 for the Defense Nuclear Agency. This work was initiated under the direction of Major T. Stong and completed under the direction of Major D. Spangler.

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1.0 INTRODUCTION

This report describes the Reverse Ballistic Tests conducted under Task 4 of the Impact and Penetration Technology Program, Contract DNA001-75-C-0101-P00001, by Avco Systems Division for the Defense Nuclear Agency (DNA).

Two series of tests were conducted. The first series consisted of tests to demonstrate that all aspects of the proposed P-2 test approach were valid. The second series consisted of two identical Reverse Ballistic Tests (RBT) of two half-scale P-2 scale model earth penetrators (EP). The two P-2 test models were designed, fabricated and instrumented by Sandia.

The objectives of the demonstration tests were:

1. Verify that the desired 1800 ft/s media projectile velocity could be achieved in Avco's existing RBT facility.
2. Verify that the structural integrity of the sandstone media projectile could be maintained under the acceleration loads associated with the desired 1800 ft/s test velocity.
3. Demonstrate that the P-2 EP models could be successfully recovered at the conclusion of testing.
4. Demonstrate that detailed photographic coverage at rates up to 14,000 frames per second could be obtained.

The demonstration tests performed to verify the above objectives are described in detail in Section 2.0 of this report.

The objectives of the P-2 RBT's were:

1. Acquire detailed strain and acceleration data for the normal impact case from an instrumentated P-2 scale model EP impacted by a sandstone projectile traveling at 1800 ft/s.
2. Verify the validity of the strain and acceleration test data acquired during the first test by performing a second P-2 model EP RBT identical to the first test and comparing the test data.
3. Recover the P-2 models at the conclusion of each test and return to Sandia for detailed examination.
4. Provide detailed test data against which predictions of structural response can be compared.

The details of the P-2 RBT's are presented in Section 3.0 of this report. The results of the tests are summarized in Section 4.0.

All tests were conducted at Avco's Reverse Ballistic Test Facility located at Otis AFB, Massachusetts. A typical test setup is shown in Figure 1. As the name implies, RBT involves ballistic tests during which the target is impacted into the earth penetrator (EP) instead of the conventional method. The setup consists of a 15.2-inch diameter smooth bore propellant driven media launcher with the test EP (target) suspended directly in front of the muzzle of the gun. The test consists of firing the media projectile at the target projectile (EP) and recording the test data of interest during the impact event.

Why use the RBT approach? Reverse ballistic testing is used in place of straight ballistic tests to reduce overall costs and to improve the detail and quality of data gathered from each test. It's principal advantage is that significant numbers of channels of instrumentation can be "hard Lined" to standard recording equipment, thereby eliminating the need for channel-limited, less reliable high "g" telemetry systems which would be required for straight ballistic shots.

Are tests performed in the reverse ballistic manner valid? The answer is yes, as long as momentum exchange is minimized and until stress wave reflections from the free surfaces of the media projectile obscures the test results. For the sandstone media projectile the useful test data recording time was approximately 500 μsec and the momentum exchange during that period for the two P-2 tests was approximately 1% of the total. Thus, the test data is considered quite valid for the first 500 μseconds after impact.

Figure 1. Reverse ballistic test setup.

2.0 DEMONSTRATION TESTS

A series of demonstrations were performed to verify that the P-2 EP tests could be performed as planned and all P-2 test objectives could be achieved.

It was initially hoped that the EP could be recovered from the catcher after each test and that the media projectile could be kept out of the catcher to minimize possible interaction and subsequent damage to the EP. However, the deflector plate intended for this purpose shattered under high velocity impact and had to be abandoned. Subsequent catcher modifications worked well in capturing the EP after each test and there was no evidence that the media projectile damaged the EP during deceleration in the catcher.

Other test objectives of demonstrating media velocities of 1800 ft/s, sandstone media integrity and improved film coverage were achieved during testing and provided the basis for the highly successful P-2 tests described in Section 3.0 of this report.

Test Hardware

Two of the recovered penetrators from the Reference 1 program were used as target projectiles. Details of these projectiles are shown in Figure 2. For Test 3, the projectile was ballasted to a total weight of 37.9 pounds, to achieve the same W/A as the P-2 penetrator model. The projectiles were instrumented with four axially oriented strain gages, installed on the OD surface 90 degrees apart at Station 11.0.

Media projectile details (external geometry identical to the Reference 1 program configuration) are shown in Figure 3. For Tests 1 and 3, 14-inch diameter x 9-inch long sandstone cylinders were cut from the San Ysidro sandstone billets supplied by Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi. These cylinders were held in the aluminum cans with a high strength concrete grout mix. The Test 2 projectile had a 4000 lb/in^2 concrete media identical to that used in the Reference 1 program as is shown in Figure 4.

The catcher details for Tests 1 and 2 are shown in Figure 5. The catcher front consisted of a pair of 4140 steel plates positioned to form a media projectile deflector wedge. The plates were 4' x 3' x 3"-thick. The catcher was filled with screened sand material. Eight 4' x 4' x 4' concrete

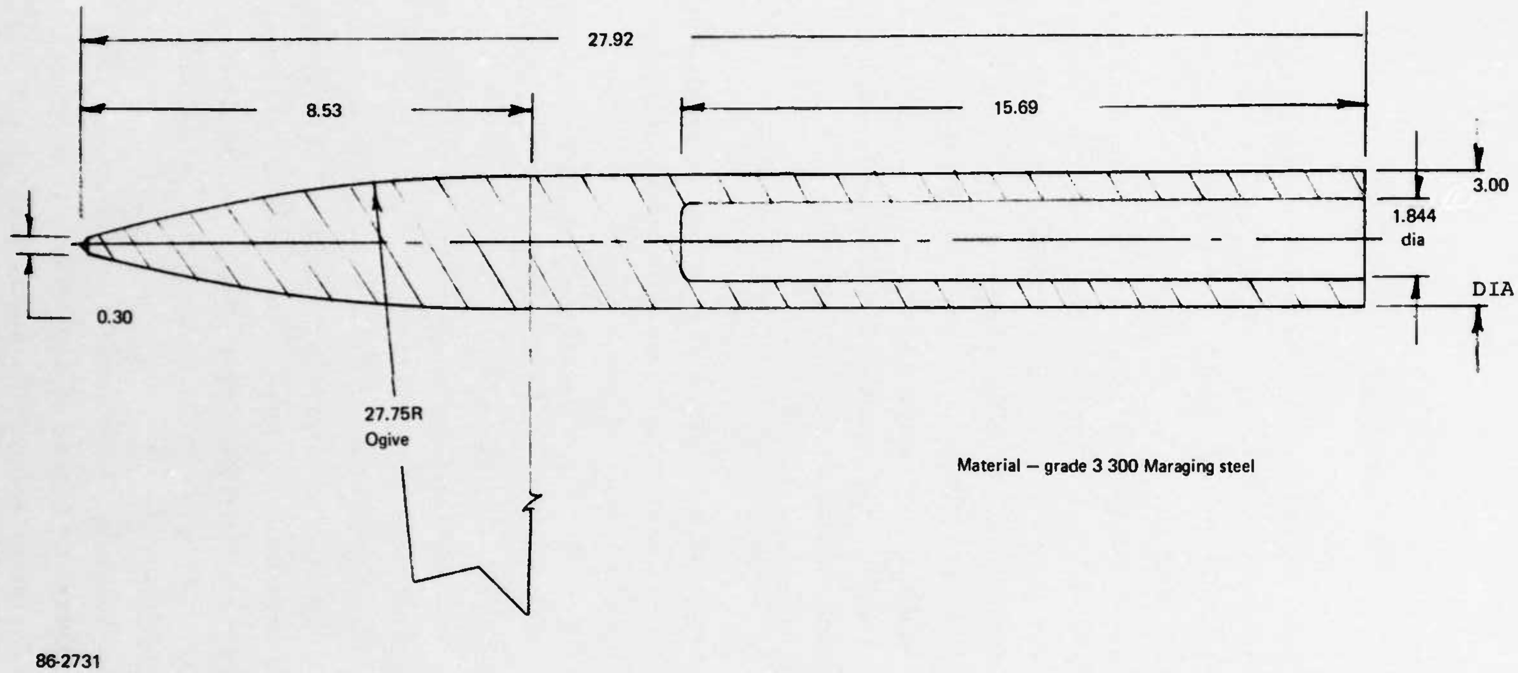

Figure 2. Schematic of reverse ballistic target projectile.

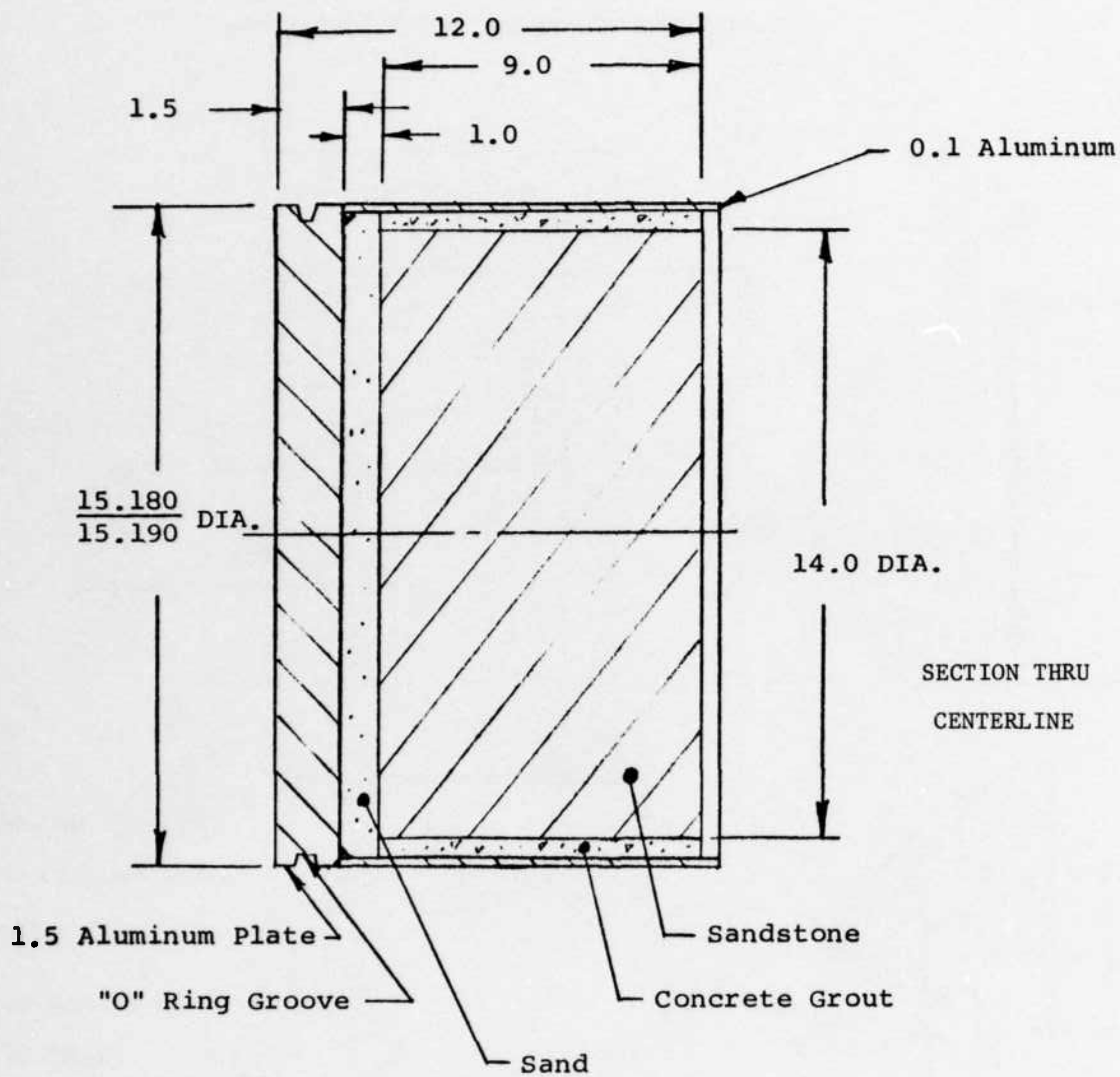

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Figure 3. Media projectile.

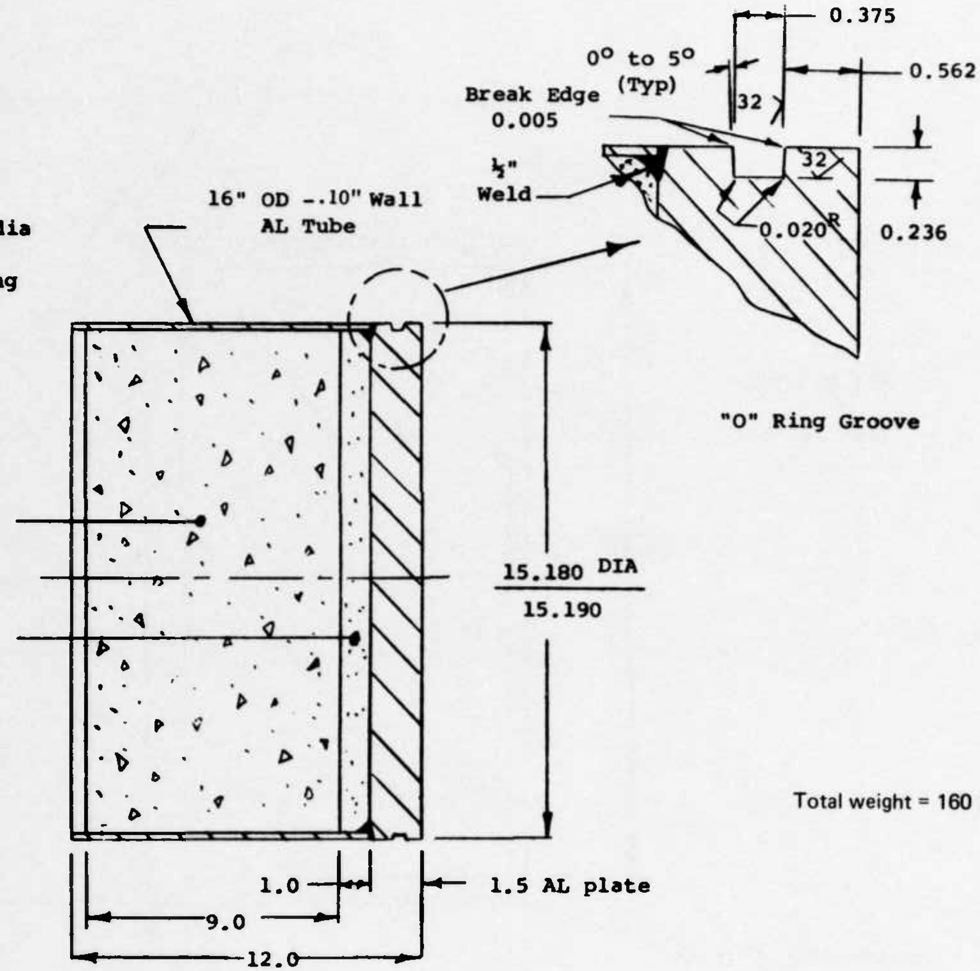
FABRICATION PROCEDURE

(1) Weld 16" OD AL Tube to 1½" AL Plate.

(2) Install Sand (1") Layer

(3) Cast In Place Concrete Media

(4) Finish Machine OD, "O" Ring Groove, etc.



Total weight = 160 lbs

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Figure 4. Schematic of thin wall aluminum media projectile.

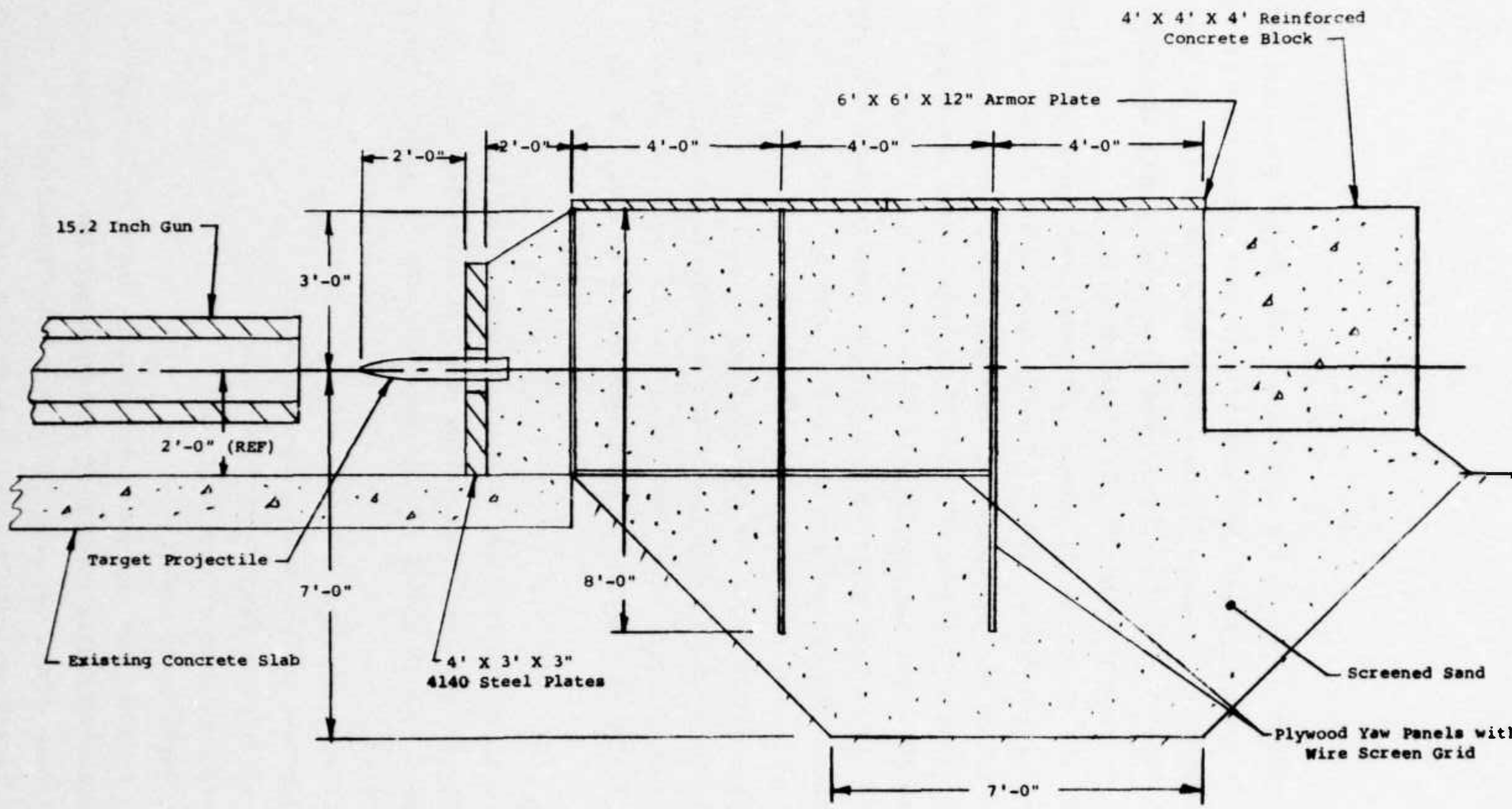

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Figure 5. Elevation profile – target projectile catcher, Tests 1 and 2.

blocks were positioned to provide a containment wall around the sides and rear of the sand. Plywood yaw panels instrumented with wire screen make circuit grids were installed in the media for determination of EP projectile position-time histories. Two 6' x 6' x 2"-thick steel armor plates were installed on top of the sand to prevent escape of the EP projectiles.

For Test 3, the EP projectile catcher was redesigned based on results observed in demonstration Tests 1 and 2. Catcher details are shown in Figure 6. The catcher was filled with screened sand material with internal dimensions increased to 20' long x 6' wide x 6' high. Soil below grade level was removed to a depth of 5 feet and backfilled with screened sand. Twelve, 4' x 4' x 4' concrete blocks were positioned to provide a containment wall around the sides and rear. The catcher top was covered with 6' x 6' steel armor plates. Sides and top of the catcher were lined with 6 x 8-inch oak timbers to preclude impact of the EP on the hard containment wall. A double layer of timbers were placed at the catcher rear. For demonstration Test 3, plywood yaw panels instrumented with wire screen make circuits were positioned on 4-foot centers in the sand media for determination of EP position-time histories.

Instrumentation

All electrical sensor data was recorded on a wide band Ampex FR 1800H transport. Data was recovered by real time playback onto electronic counters and oscilloscopes. The following signals were recorded for each of the three demonstration tests.

1 - PCB 118 pressure gage in breech plug

2 - Velocity make circuit switches at gun muzzle

1 - Contact switch on target projectile nose

5 - Yaw card grid make circuit switches

4 - Strain gages on EP model.

Photograph coverage was improved over previous tests to provide high resolution position-time data for the EP media projectiles. A Hi-Cam high speed motion picture camera was positioned as shown schematically in Figure 7 so as to record target projectile position-time data after media projectile impact. A high speed shutter was used to provide a sharp object image. The target and media projectiles were back-lighted using a translucent diffuser

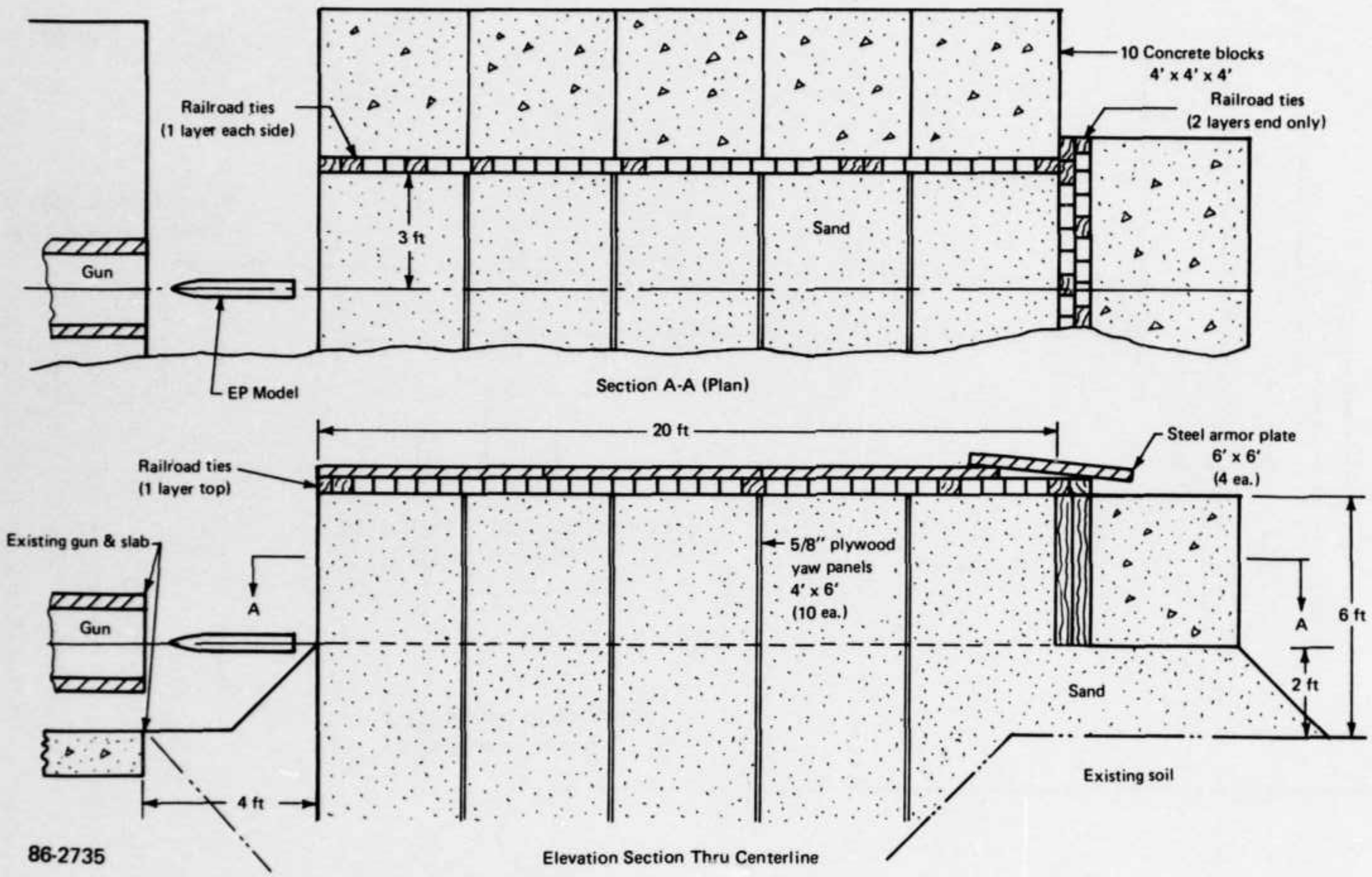

Figure 6. Projectile catcher assembly.

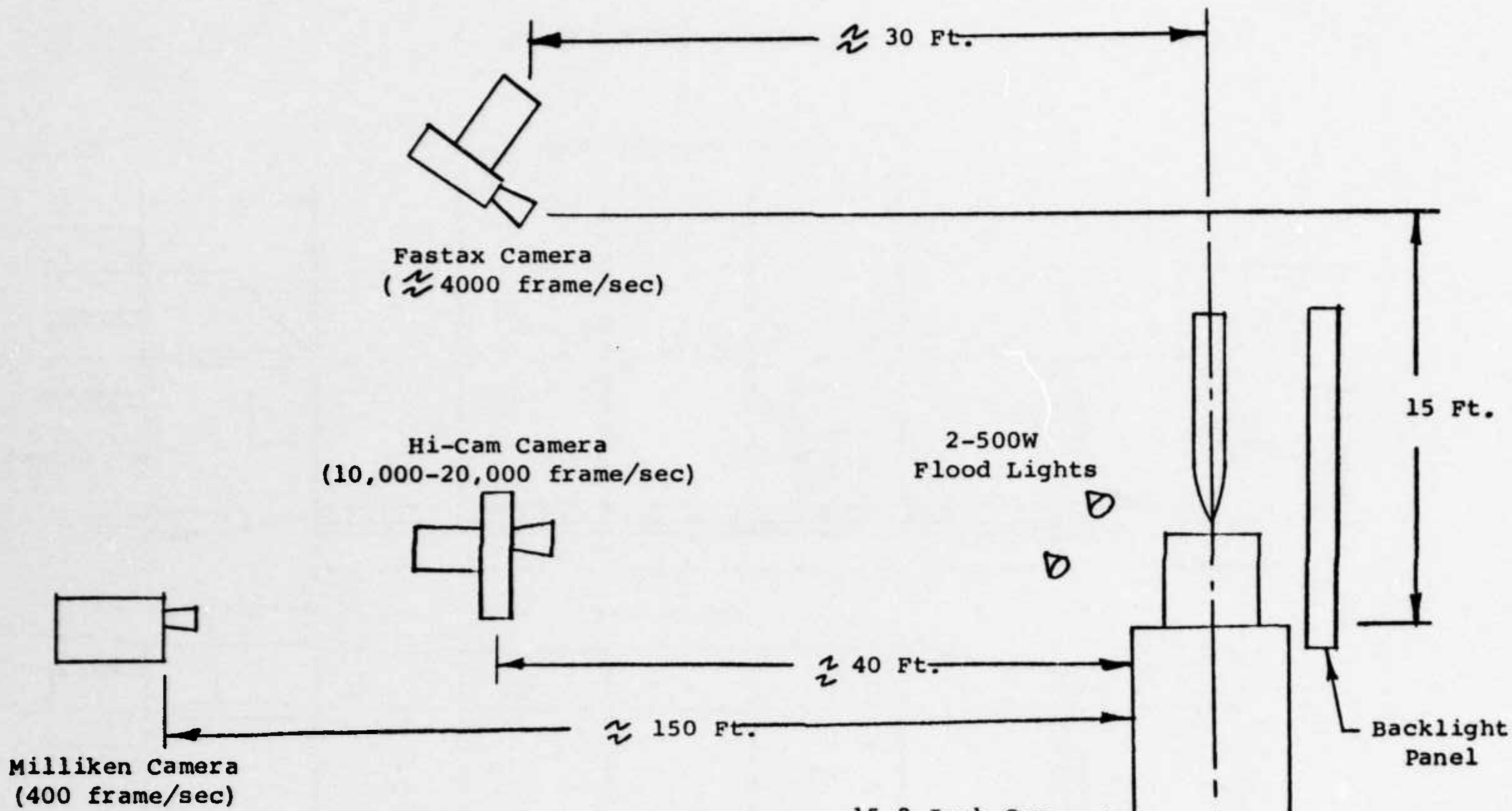

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Figure 7. Schematic of camera positions.

panel, an array of approximately 20 FF-33 long duration flash bulbs and a reflector panel. A sequencer was used to trigger the flash bulbs and initiate the propellant charge at the proper time so the impact event took place during peak illumination output of the flash bulbs.

Additionally, a Fastax high speed motion picture camera was employed to observe the impact event and a Milliken high speed camera was employed to observe the overall test event.

Results and Discussion

Test results are summarized in Table 1.

TABLE 1. SUMMARY DNA REVERSE BALLISTIC DEMONSTRATION TESTS

Test	Date	Media	Impact velocity (probes) (ft/s)	Impact velocity (camera) (ft/s)	Impact velocity (avg) (ft/s)	Axial peak strain (avg) ($\mu\epsilon$)	Peak model velocity (ft/s)	Time peak velocity (μsec)	Angle of attack	Catcher penetration (ft)
DD-1	3/30/76	Sandstone	244	--	244	700	~200	--	0^o	11.5
DD-2	3/31/76	Concrete	1767	1733	1750	~2500	105	600	10^o	4
DD-3	6/3/76	Sandstone	1720	1791	1755	3000	124	700	0^o	4

For Test 1, a charge of 20 pounds of WC 870 propellant was used. Pretest interior ballistic analyses (Figure 8) indicated that this propellant would produce a higher velocity than previously used propellants at a given limit breech pressure, and therefore be more suitable for achieving the desired 1800 ft/s impact velocity. Apparently, the graphite coating deterrent on WC 870, retards ignition at low breech pressures (i.e., less than 30,000 lb/in^2) and consequently, the propellant failed to ignite properly, resulting in a velocity of only 244 ft/s.

For Tests 2 and 3, the propellant was changed to 18 pounds of IMR 4895 (Figure 9 analysis) resulting in respective 1750 and 1755 ft/s impact velocities. Breech pressures were 12,000 and 15,000 lb/in^2 for the 2 tests, being slightly above nominal operating pressure but well below a level which would produce gun barrel yielding or failure. These results indicated that the desired 1800 ft/s velocity could be achieved for the P-2 tests with the existing gun launch facility.

As indicated previously, a back-lighting panel and additional high speed motion pictures cameras were added to provide EP model positive vs. time data,

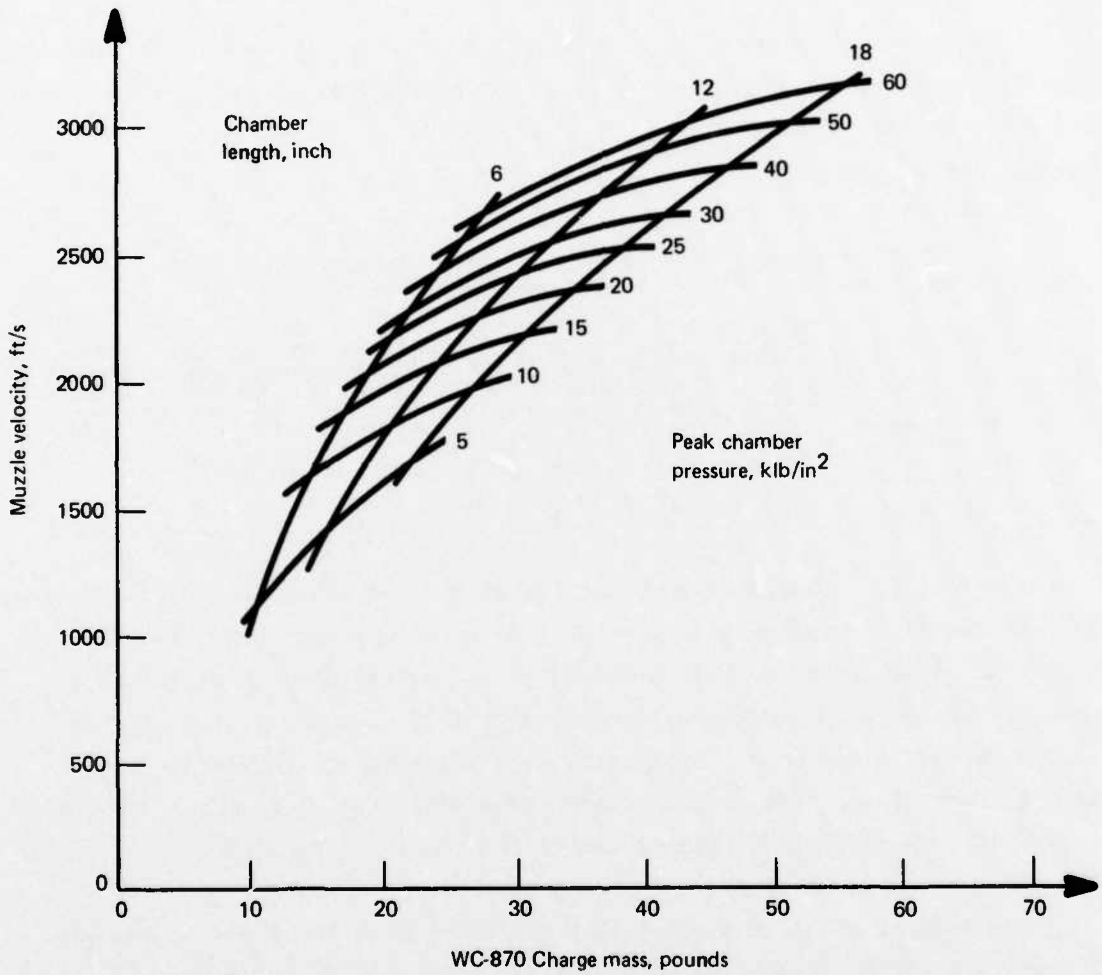

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Figure 8. Fifteen inch gun ballistics parameters for 160 pound projectiles.

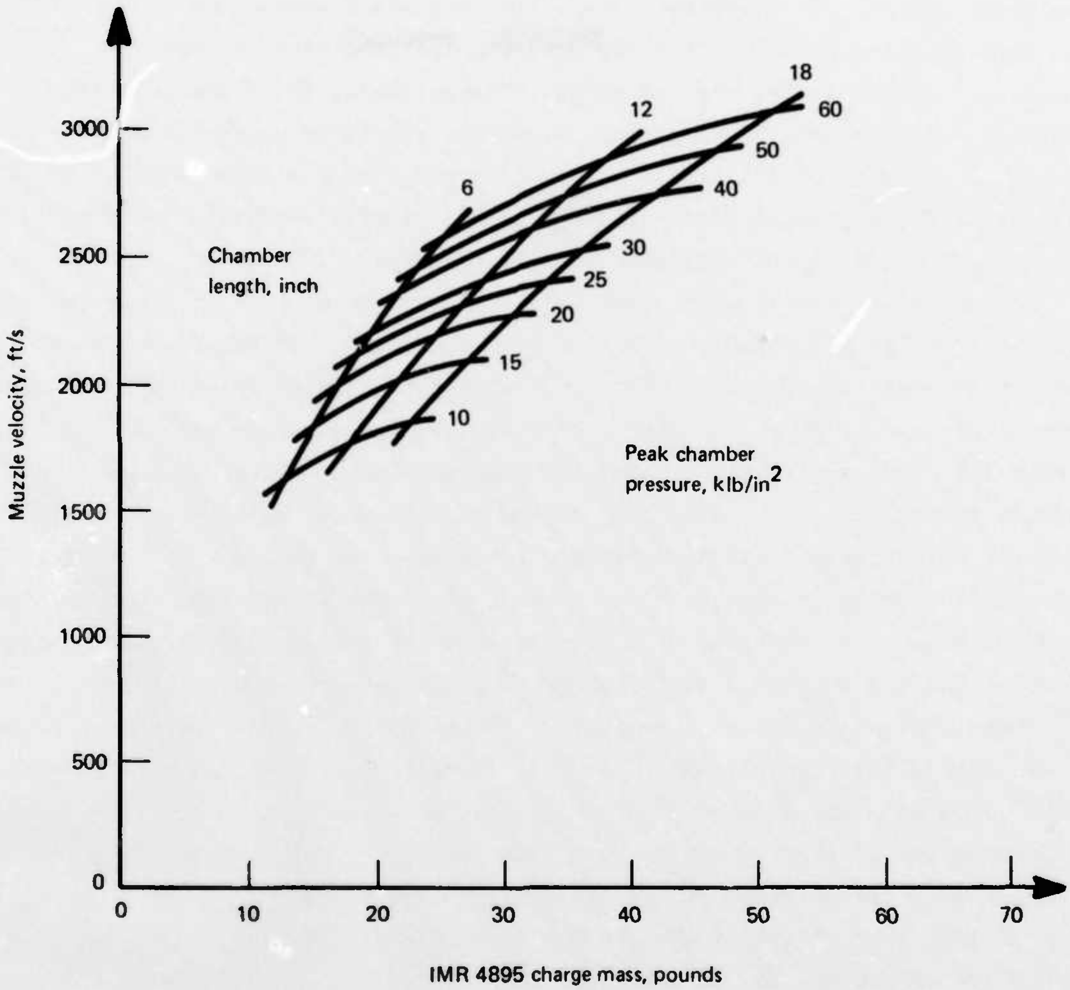

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Figure 9. Fifteen inch gun ballistics parameters for 160 pound projectiles.

and also to provide higher resolution back up impact velocity data. Figures 10 and 11 show motion of the EP model base for Tests 2 and 3, respectively. For both tests, motion could be followed for approximately 1 millisecond after impact at which time the EP model was completely masked by concrete or sandstone debris. The quality of the high speed film coverage substantiated the back-lighting technique and provided the tool necessary to measure momentum transfer during the P-2 tests. Inspection of the films indicated that both the concrete media in Test 2 and the sandstone media in Test 3 showed no evidence of failure as a result of gun launch environments. The OD surface of the media projectile did not expand significantly or fracture until approximately 500 to 600 microseconds after impact.

As noted previously there were four strain gages on each of the demonstration projectiles and they were applied to the external surface in the axial direction at Station 11.0 at 0°, 90°, 180° and 270°. Strain vs. time data for the three tests are shown in Figures 12 through 14. As expected, strains in Test 1 were low level as a result of the low impact velocity. Average peak axial strains for Tests 2 and 3 were 2000 to 3000 microstrain, which are consistent with the data obtained in the Reference 1 program. If fracture of the media had occurred prior to impact, these peak levels would likely have been significantly lower. Thus both the film coverage and the strain data provided confidence that the sandstone media integrity was maintained during launch.

Data showing EP model position vs. time in the catcher are shown in Figures 15 through 17 for Tests 1 and 2. In Test 1 the EP did not fully penetrate the media projectile and achieved a peak velocity of approximately 200 ft/s. The EP entered the catcher tail first and penetrated to a depth of 11.5 feet, maintaining a nearly straight line trajectory with minimal angle of attack.

In Test 2 the EP had a 10-degree nose down angle of attack and was driven aft and down. The EP nose impacted the concrete slab, causing some bending of the EP body, and the EP subsequently entered the catcher penetrating to a depth of approximately 4 feet as shown in Figure 17. Impact of the media projectile destroyed the 3 inch thick 4140 deflector plates. Pretest and post-test photos of the plates are shown in Figures 18 and 19, respectively.

In Test 3 the EP model penetrated approximately 4 feet with the EP model final position near the trajectory centerline and turned approximately 90 degrees. No permanent bending of the EP model was detected.

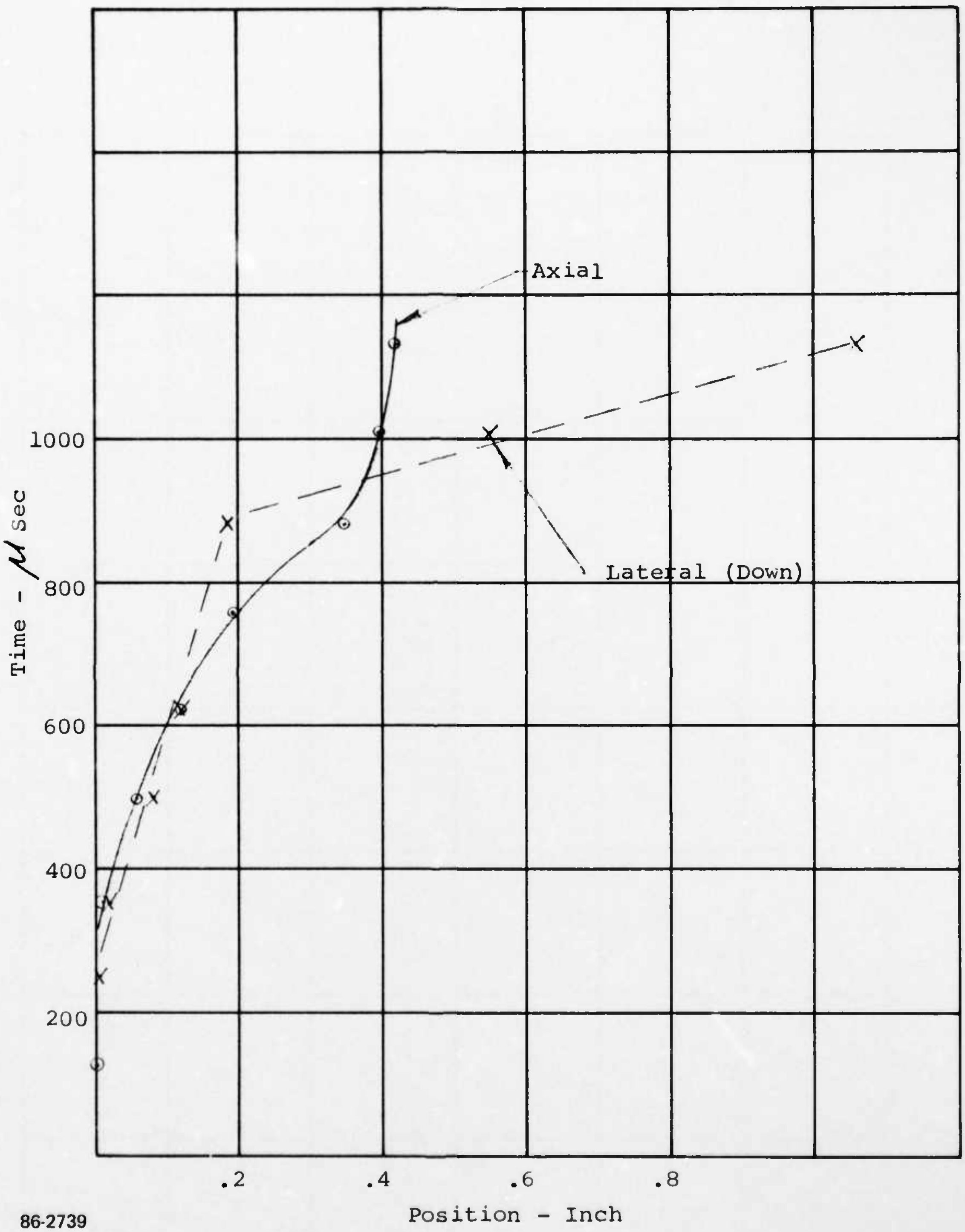

Figure 10. Reverse ballistic demonstration Test 2 — model base position vs. time.

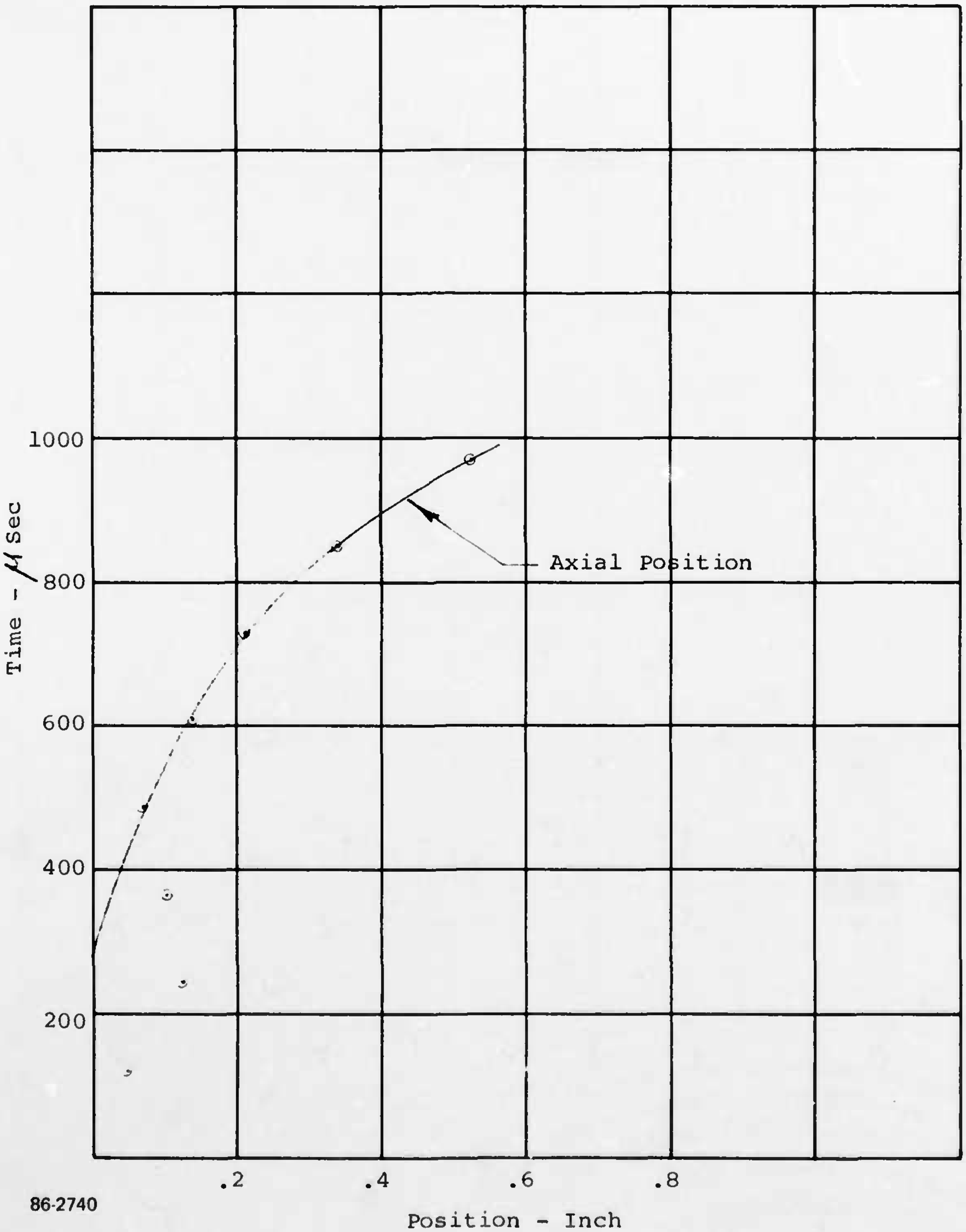

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Figure 11. Reverse ballistic demonstration Test 3 — model base position vs. time.

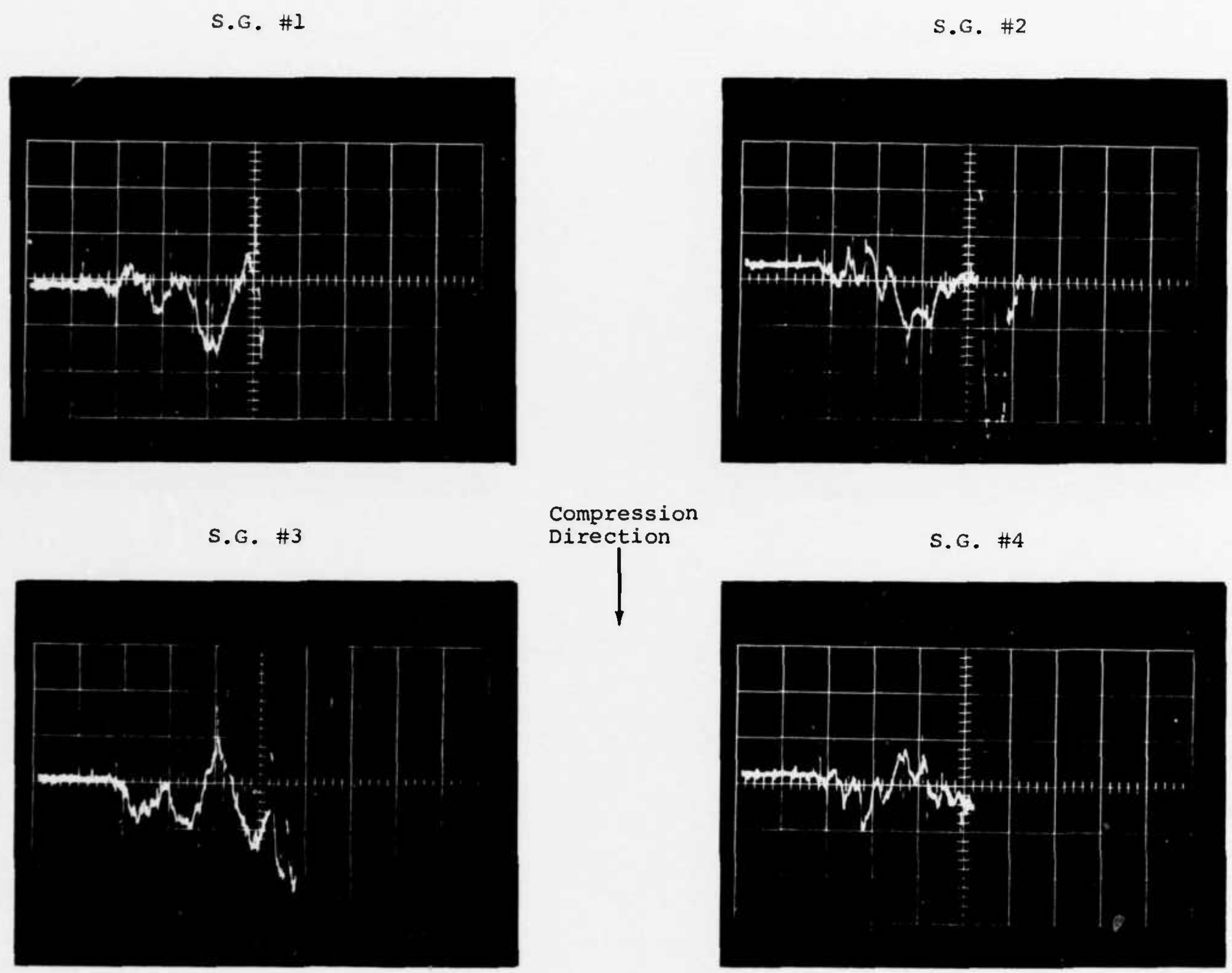

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Figure 12. Demonstration Test 1, sandstone — 244 ft/s normal impact. (500 μE/cm, 1 μs/cm)

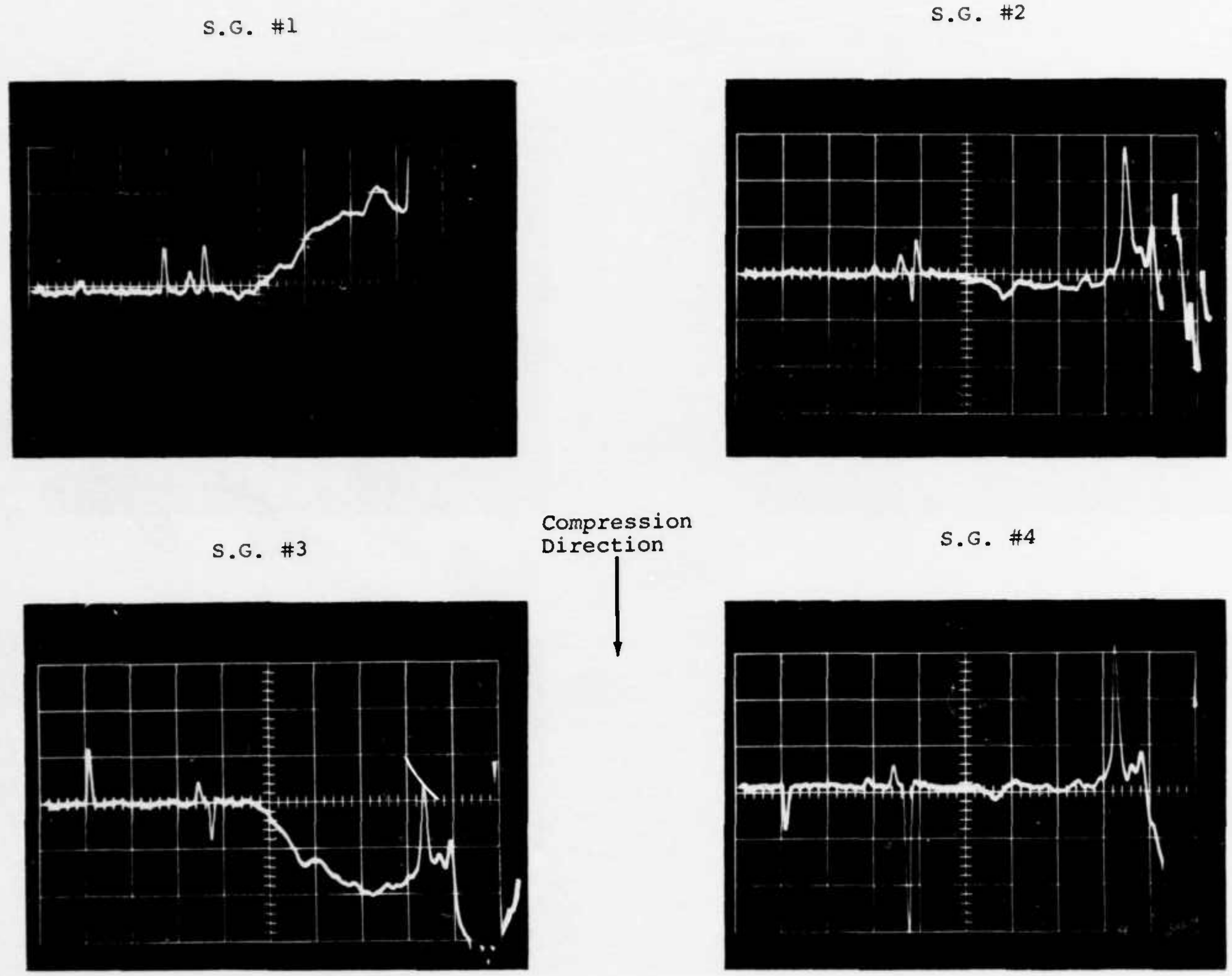

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Figure 13. Demonstration Test 2, concrete – 1767 ft/s – 10° angle of attack.
(5000 μE/cm, 100 μs/cm)

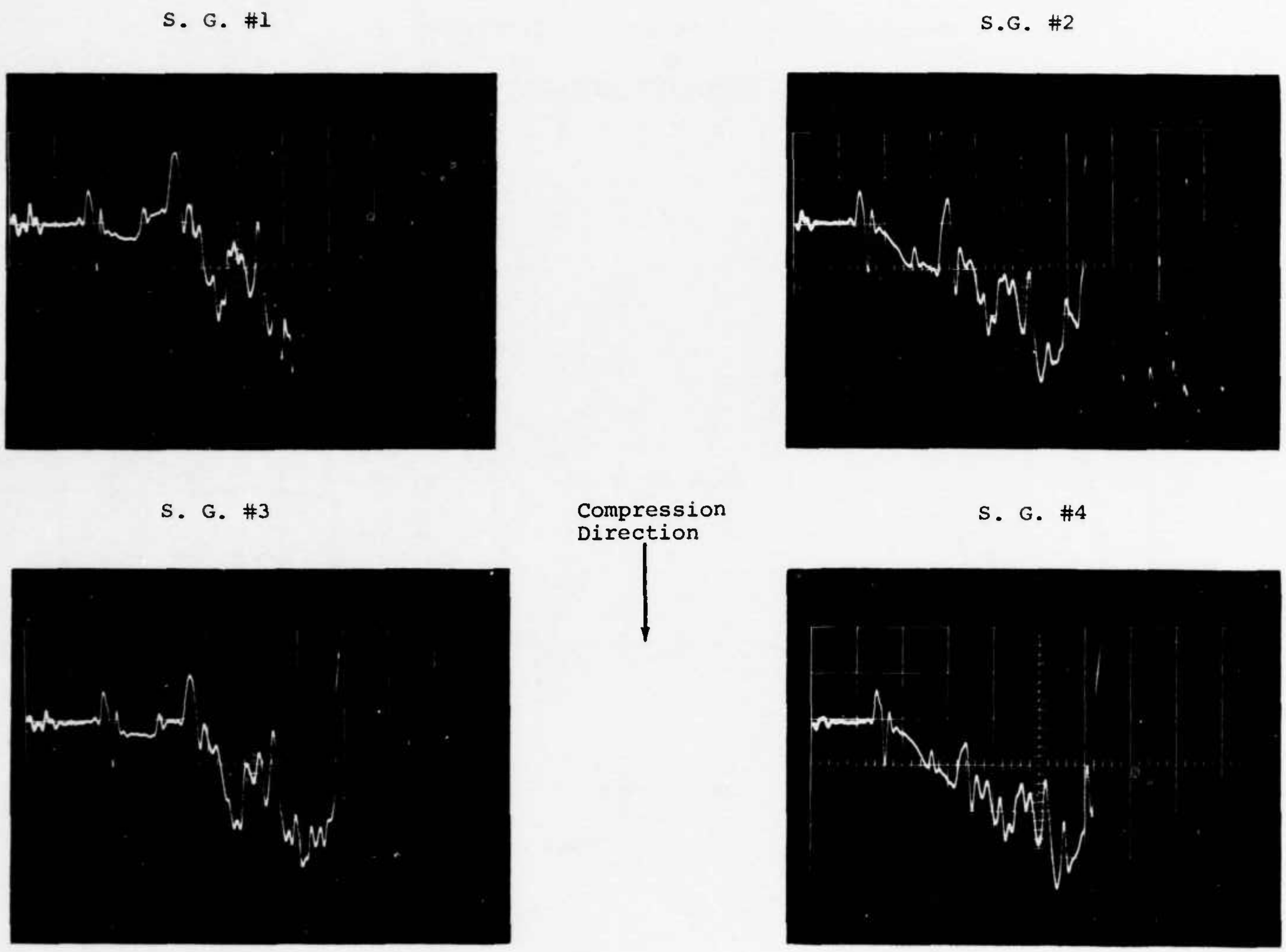

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Figure 14. Demonstration Test 3, sandstone – 1755 ft/s – 0° angle of attack.
(2000 μE/cm, 200 μs/cm)

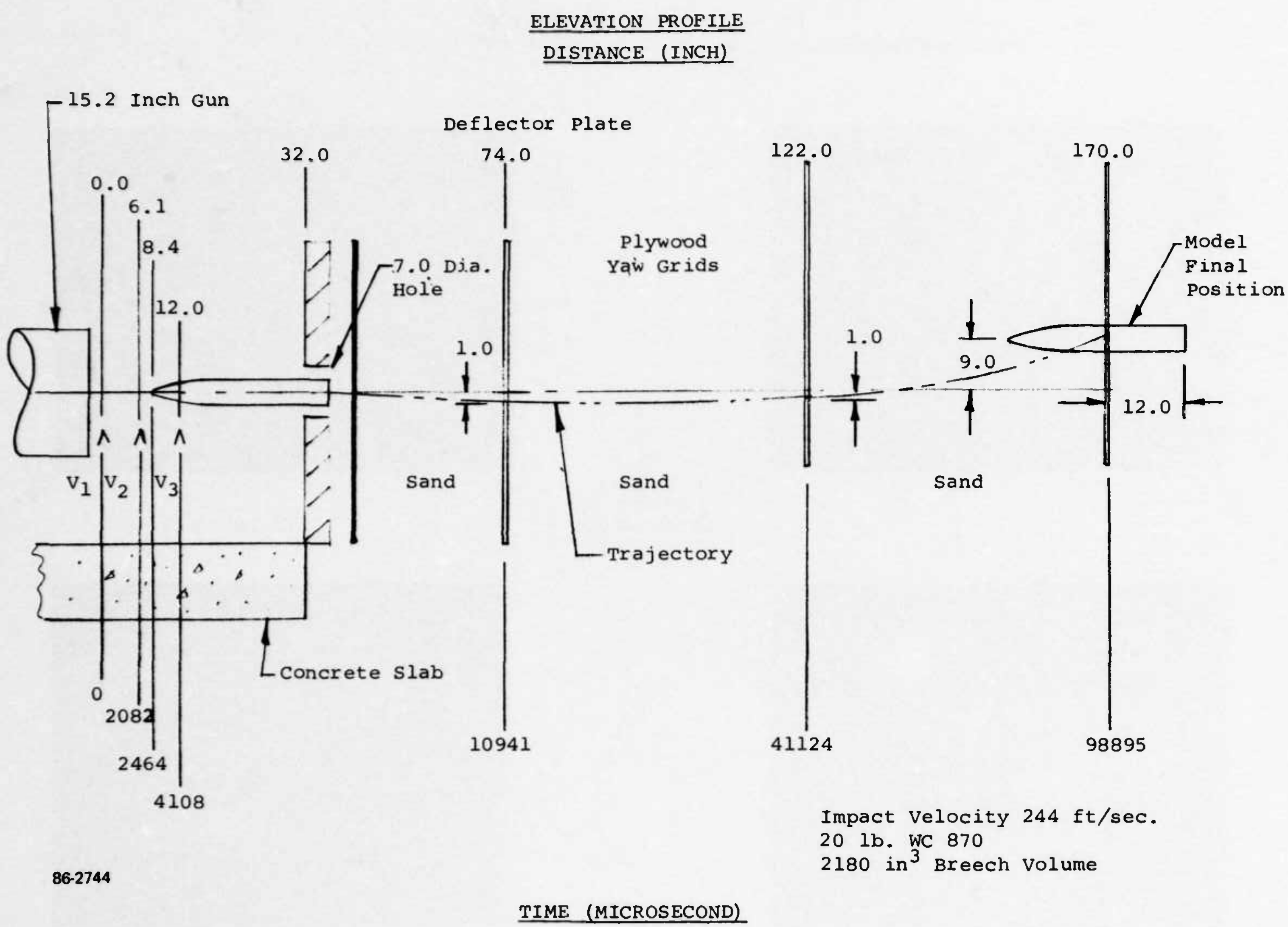

Figure 15. Demonstration Test 1 – 3/30/76, normal impact.

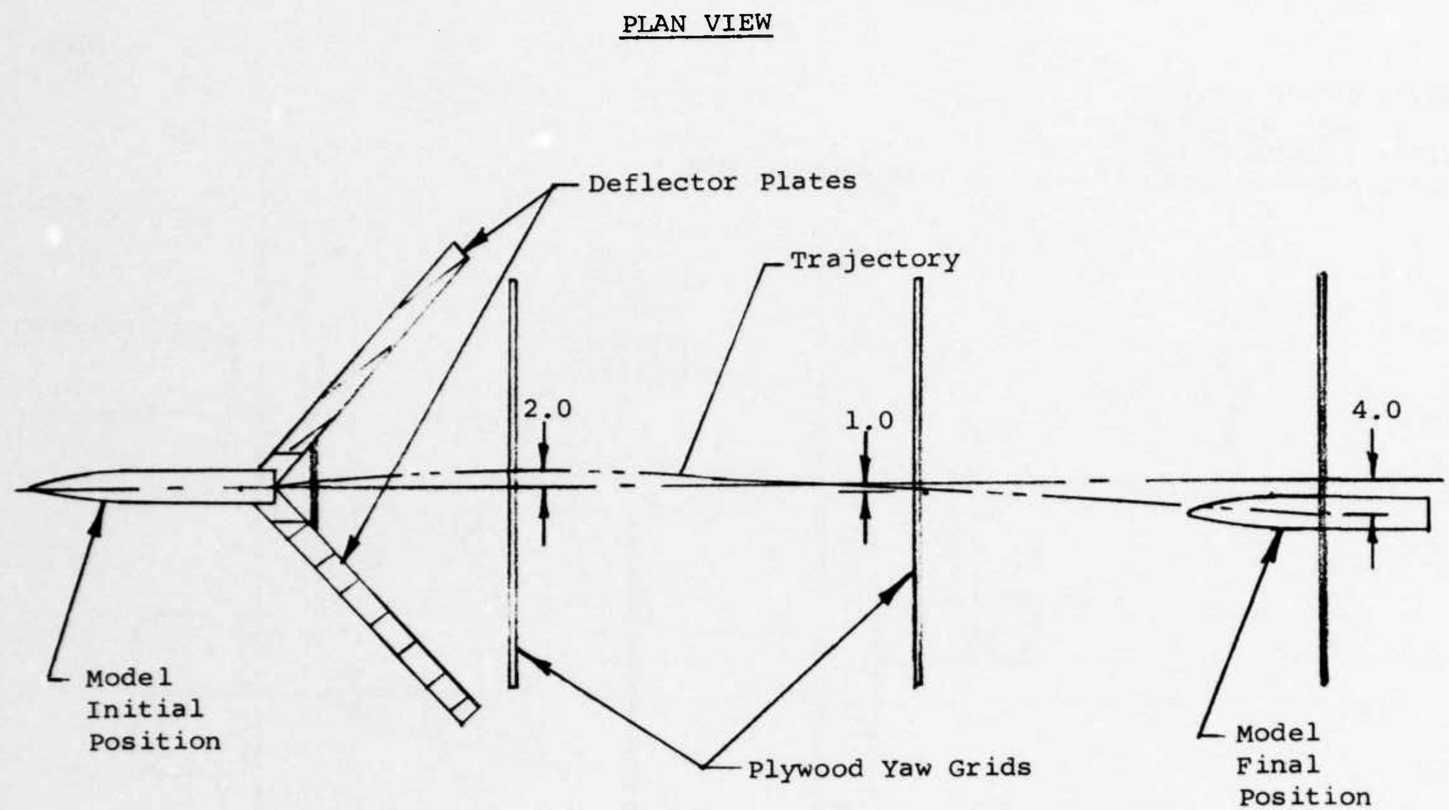

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Figure 16. Demonstration Test 1 – 3/30/76, normal impact.

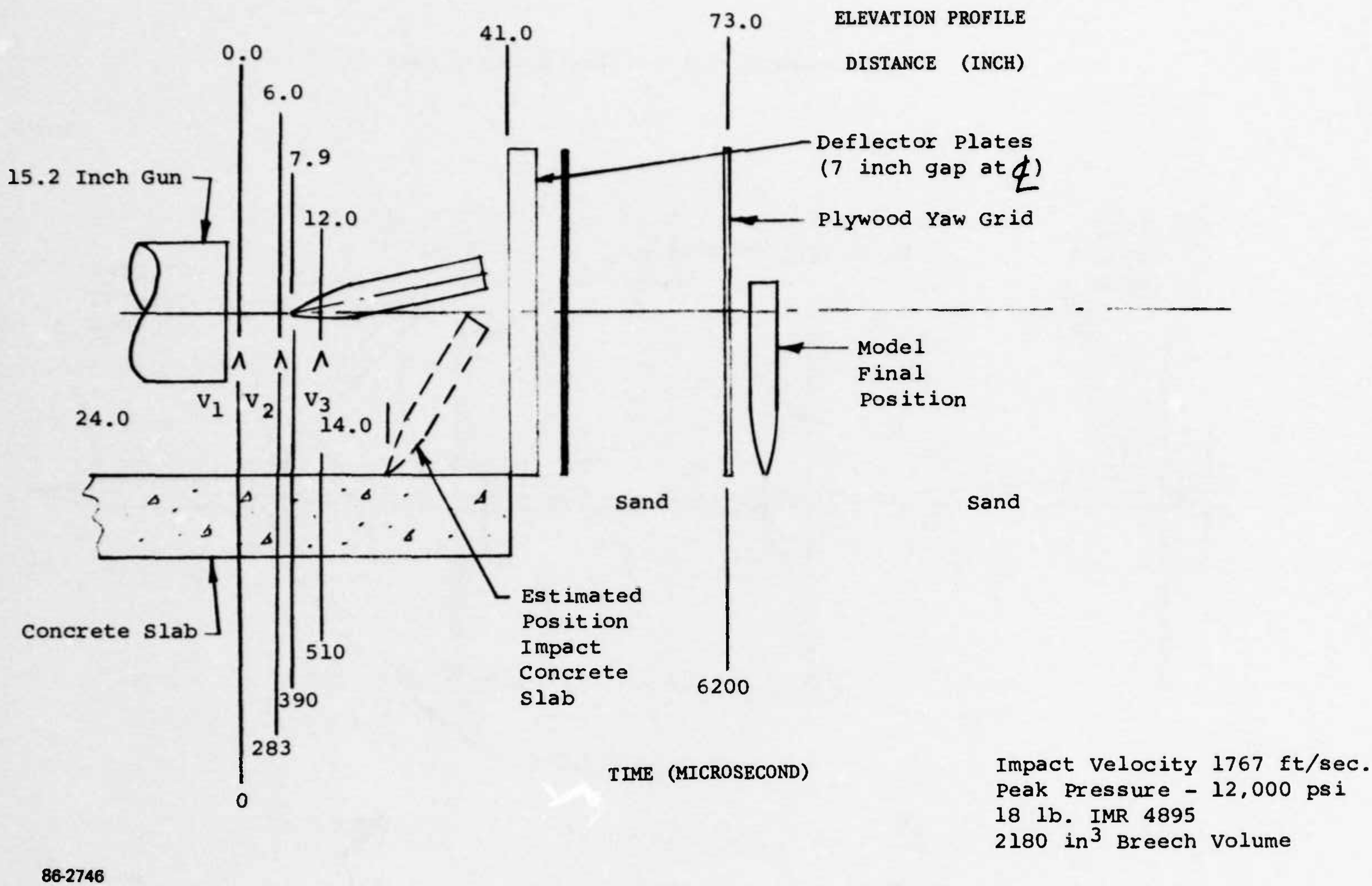


Figure 17. Demonstration Test 2 – 3/30/76, 10° angle of attack.

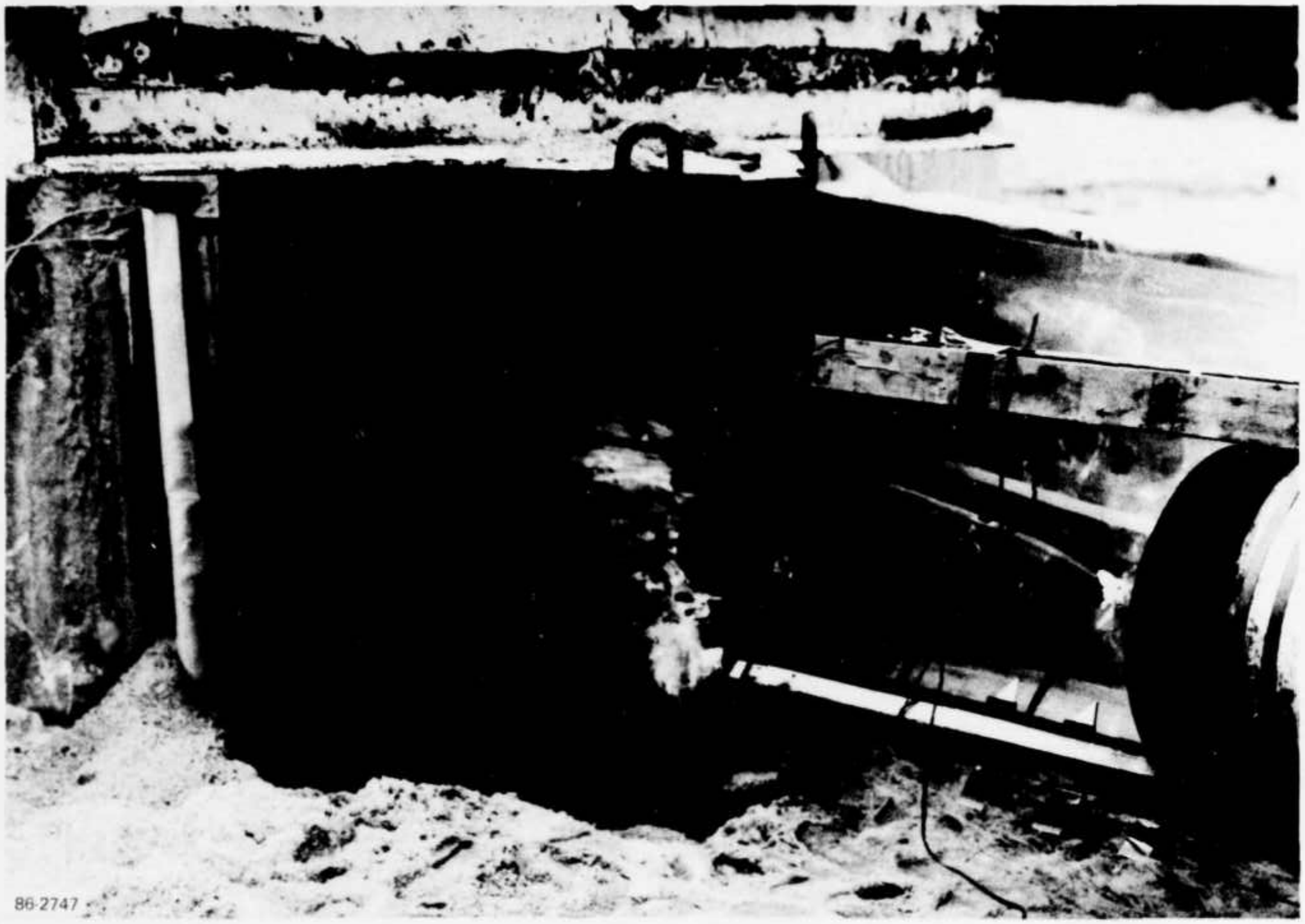


Figure 18. Pretest view of demonstration Test 2 showing EP model and deflector plates.

Figure 19. Post test view of demonstration Test 2 showing fractured deflector plates.

3.0 REVERSE BALLISTIC TESTS - P-2 PENETRATOR

The identical RBT's of half-scale P-2 EP models were performed. The models were impacted with sandstone media projectiles traveling at approximately 1800 ft/s. The EP's were oriented normal to the media projectiles for both tests. A total of 36 strain gages and 5 accelerometers were monitored on each test.

All test objectives were achieved in that extensive detailed strain and acceleration data was recorded on both tests; the data acquired on both tests was comparable and closely approximated pretest predictions. The EP's were recovered intact after each test.

Valid test data was acquired from 95 percent of the strain gages and 60 percent of the accelerometer channels for both tests. Excellent photographic coverage was acquired from both tests permitting accurate assessments of momentum transfer from the media projectile to the target EP. The catcher functioned as designed by capturing both EP's after testing without inducing significant damage.

Test Hardware

Two earth penetrator scale models were fabricated and instrumented by Sandia, Albuquerque. Details and instrumentation locations are described in Sandia Drawing S17186. (See Figure 20.) Overall dimensions for the models are: length 32.0 inches, base diameter 3.35 inches, and weight 47.23 pounds. Each model was instrumented with 36 strain gages, 5 piezo-resistive accelerometers and two passive accelerometers. Locations of the active sensors are listed in Table 2 and Figure 20.

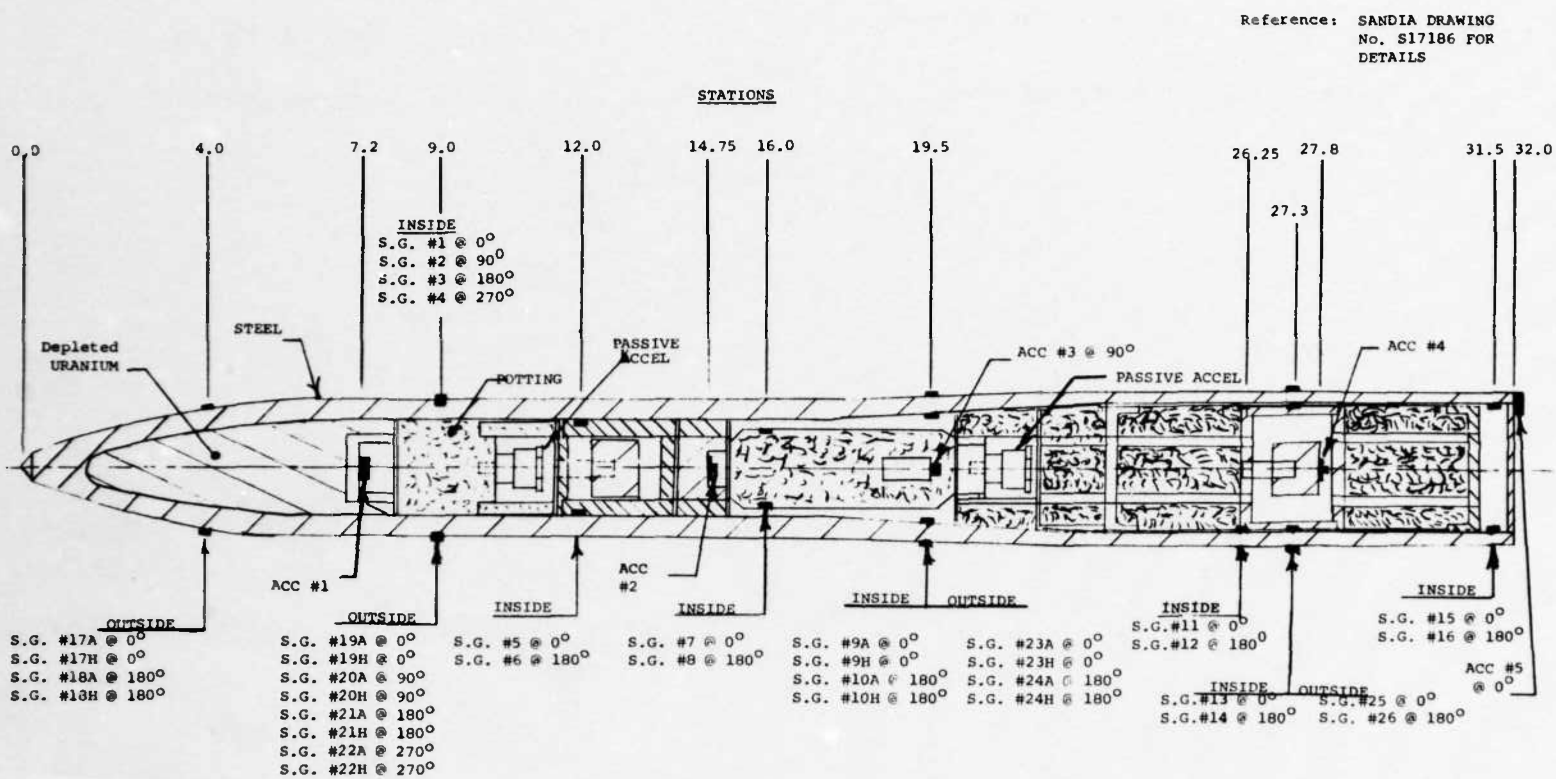
The sandstone media projectile details are presented in Figure 21. Fourteen-inch diameter by nine-inch long San Ysidro sandstone cylinders were cut from billets supplied by Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi. The space between the cylinder O.D. and aluminum wall I.D. was filled with a 4000 lb/in^2 concrete grout mix. A 1-inch thick dry sand shock cushion separated the sandstone cylinder base from the 1.5-inch thick aluminum projectile base.

The EP projectile catcher details are shown in Figure 22. The catcher was filled with screened sand material and had internal dimensions of

TABLE 2. P-2 REVERSE BALLISTIC TEST INSTRUMENTATION

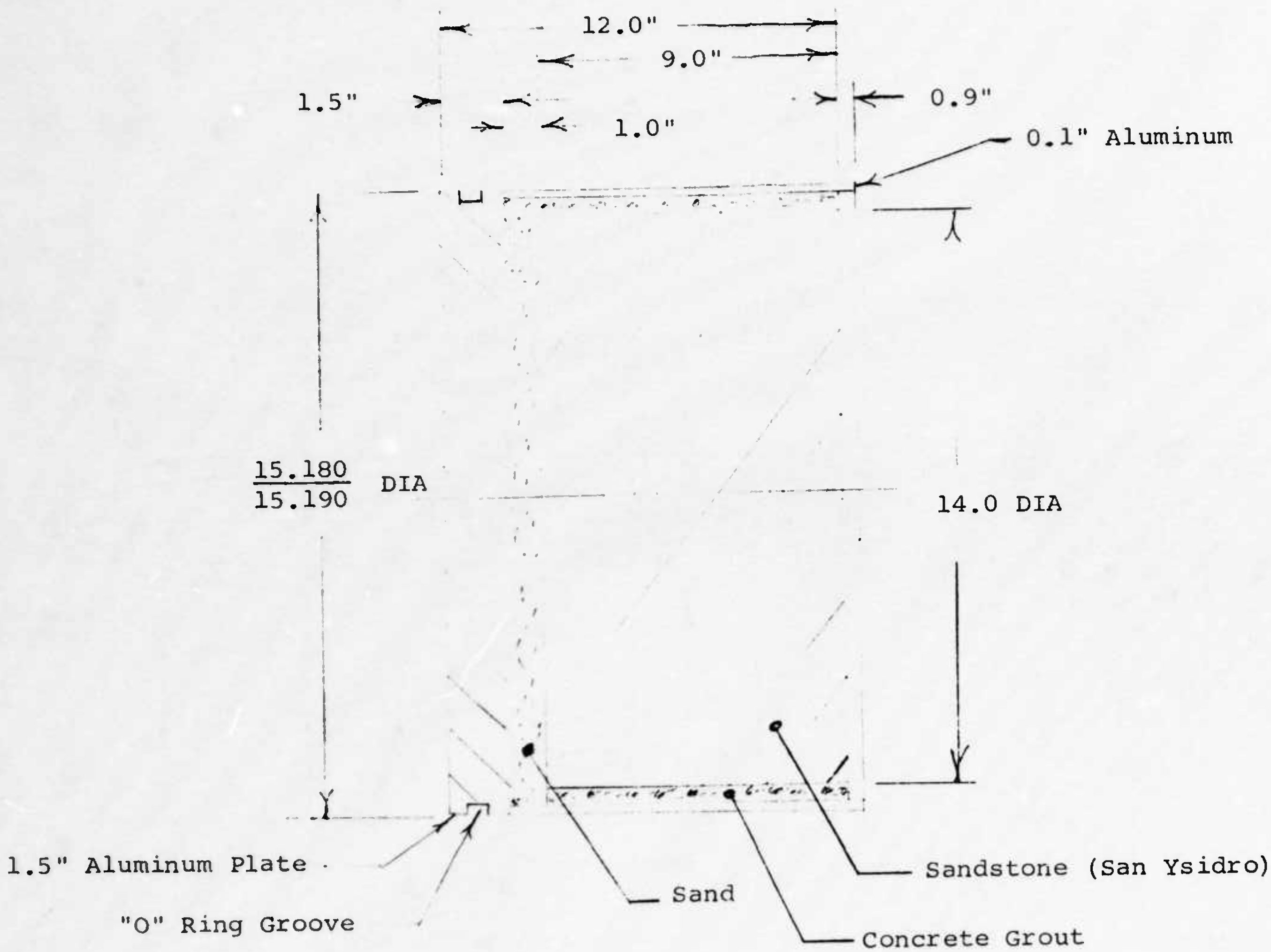
Channel number	Sensor type and number	Station (in)	Meridian (deg)	Orientation	Location	Band edge (μs)	Tape trk. no.	PPSA-1 Time to initial strain response following scope sweep start	PPSA-1 Time to impact from scope sweep start* (μs)	PPSA-2 Time to initial strain response following scope sweep start	PPSA-2 Time to impact from scope sweep start* (μs)
1	S.G. S-1	9.0	0	Axial	ID Can	5K	1	575	510	455	380
2	S.G. S-2	9.0	90	Axial	ID Can	5K	1	575	510	455	380
3	S.G. S-3	9.0	180	Axial	ID Can	5K	1	575	510	455	380
4	S.G. S-4	9.0	270	Axial	ID Can	5K	1	575	510	455	380
5	S.G. S-5	12.0	0	Axial	Payload	2K	1	600	510	500	380
6	S.G. S-6	12.0	180	Axial	Payload	2K	2	550	441	400	313
7	S.G. S-7	16.0	0	Axial	OD Pot	10K	2	550	441	460	313
8	S.G. S-8	16.0	180	Axial	OD Pot	10K	2	550	441	460	313
9	S.G. S-9A	19.5	0	Axial	ID Can	6K	2	570	441	460	313
10	S.G. S-9H	19.5	0	Circ	ID Can	6K	2	570	441	460	313
11	S.G. S-10A	19.5	180	Axial	ID Can	6K	3	610	509	500	381
12	S.G. S-10H	19.5	180	Circ	ID Can	6K	3	610	509	500	381
13	S.G. S-11	26.25	0	Axial	Payload	3K	3	680	509	--	381
14	S.G. S-12	26.25	180	Axial	Payload	3K	3	680	509	590	381
15	S.G. S-13	27.3	0	Axial	ID Payload	1K	3	700	509	620	381
16	S.G. S-14	27.3	180	Axial	ID Payload	1K	4	640	440	600	314
17	S.G. S-15	31.5	0	Axial	ID Can	1K	4	--	440	600	314
18	S.G. S-16	31.5	180	Axial	ID Can	1K	4	--	440	600	314
19	S.G. S-17A	4.0	0	Axial	OD Shell	5K	4	470	440	340	314
20	S.G. S-17H	4.0	0	Circ	OD Shell	5K	4	470	440	340	314
21	S.G. S-18A	4.0	180	Axial	OD Shell	5K	5	550	510	395	382
22	S.G. S-18H	4.0	180	Circ	OD Shell	5K	5	--	510	395	382
23	S.G. S-19A	9.0	0	Axial	OD Shell	4K	5	570	510	420	382
24	S.G. S-19H	9.0	0	Circ	OD Shell	4K	5	570	510	420	382
25	S.G. S-20A	9.0	90	Axial	OD Shell	4K	5	--	510	420	382
26	S.G. S-20H	9.0	90	Circ	OD Shell	4K	6	500	444	370	315
27	S.G. S-21A	9.0	180	Axial	OD Shell	4K	6	500	444	370	315
28	S.G. S-21H	9.0	180	Circ	OD Shell	4K	6	500	444	370	315
29	S.G. S-22A	9.0	270	Axial	OD Shell	4K	6	500	444	370	315
30	S.G. S-22H	9.0	270	Circ	OD Shell	4K	6	500	444	370	315
31	S.G. S-23A	19.5	0	Axial	OD Shell	3K	7	615	509	475	385
32	S.G. S-23H	19.5	0	Circ	OD Shell	3K	7	615	509	475	385
33	S.G. S-24A	19.5	180	Axial	OD Shell	3K	7	615	509	475	385
34	S.G. S-24H	19.5	180	Circ	OD Shell	3K	7	615	509	475	385
35	S.G. S-25	27.3	0	Axial	OD Shell	2K	7	620	509	520	385
36	S.G. S-26	27.3	180	Axial	OD Shell	2K	8	540	447	465	317
37	ACC 1	7.20		Axial		50 Kg	9		490		376
38	ACC 2	14.75		Axial		30 Kg	10		430		316
39	ACC 3	19.5	90	Axial	Stl Comp	30 Kg	11		486		372
40	ACC 4	27.8		Axial	Aft Payload	40 Kg	14		428		314
41	ACC 5	32.0	0	Axial	End Shell	50 Kg	13		484		370

Media Projectile Velocity PPSA-1 Test = 1920 ft/s
Media Projectile Velocity PPSA-2 Test = 1770 ft/s
*Scope sweep initiated by Velocity Probe 1



86-2749

Figure 20. Instrumentation location on Sandia EP projectile.



86-2750

Figure 21. Sandstone media projectile for DNA reverse ballistic tests.

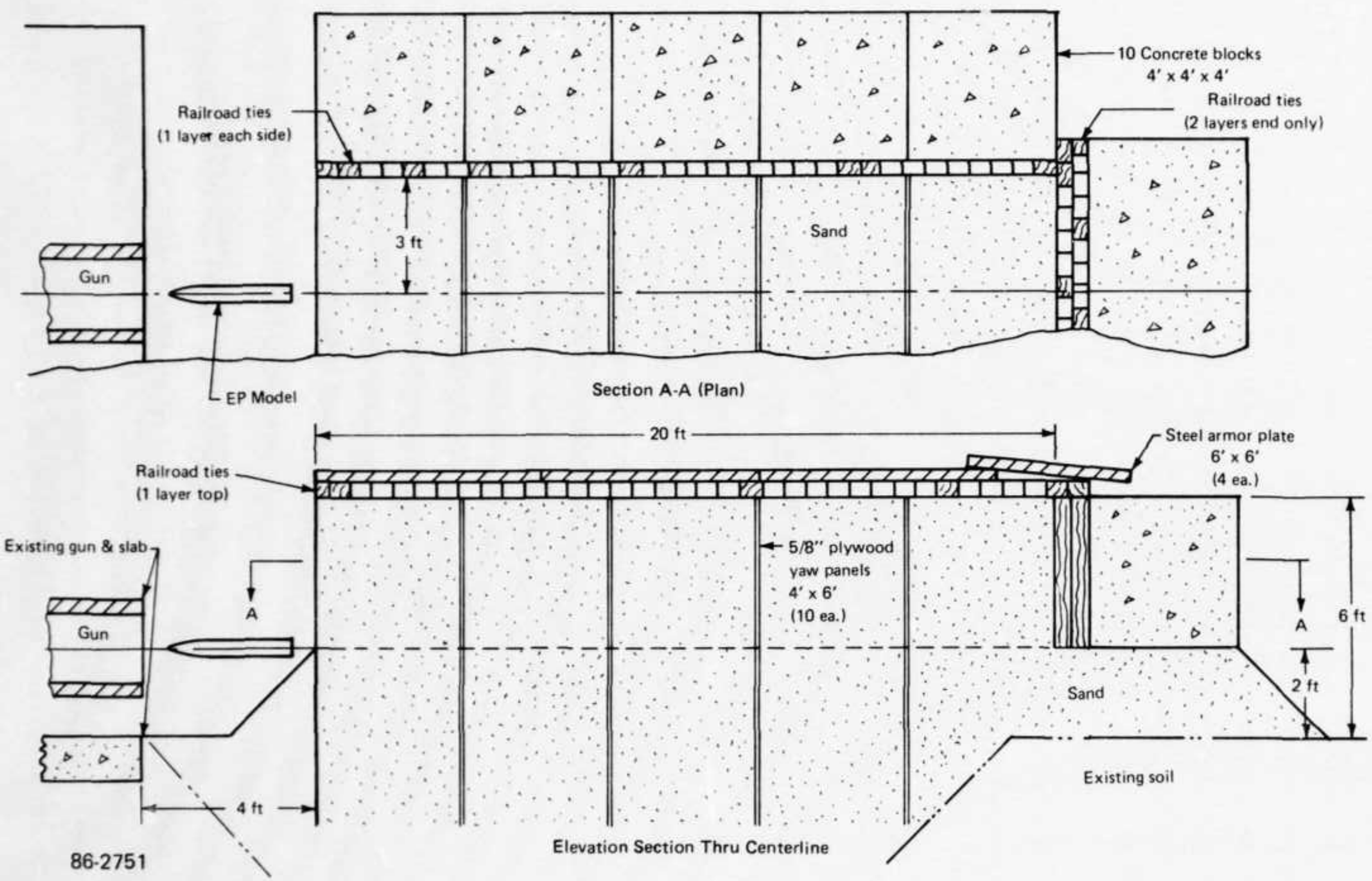


Figure 22. Projectile catcher assembly.

20' x 6' x 6'. Soil below grade level was removed to a depth of 5 feet and backfilled with screened sand. Sides and top of the catcher were lined with railroad ties to prevent impact of the EP on a hard media surface. A double layer of ties were placed at the rear of the catcher. Twelve 4' x 4' x 4' concrete blocks were positioned to provide a containment wall around the sides and rear. The catcher top was covered with 6' x 6' steel armor plates. Plywood yaw panels (10 ea.) were used to determine the EP trajectory in the catcher.

A powder charge of 1 pound FFG black powder primer and 18 pounds of IMR 4895 rifle powder encased in an 8-inch howitzer powder bag was used for both tests. A chamber volume of 2180 in^3 was used to obtain a nominal velocity of 1800 ft/s at a nominal breech pressure of 13,000 lb/in^2.

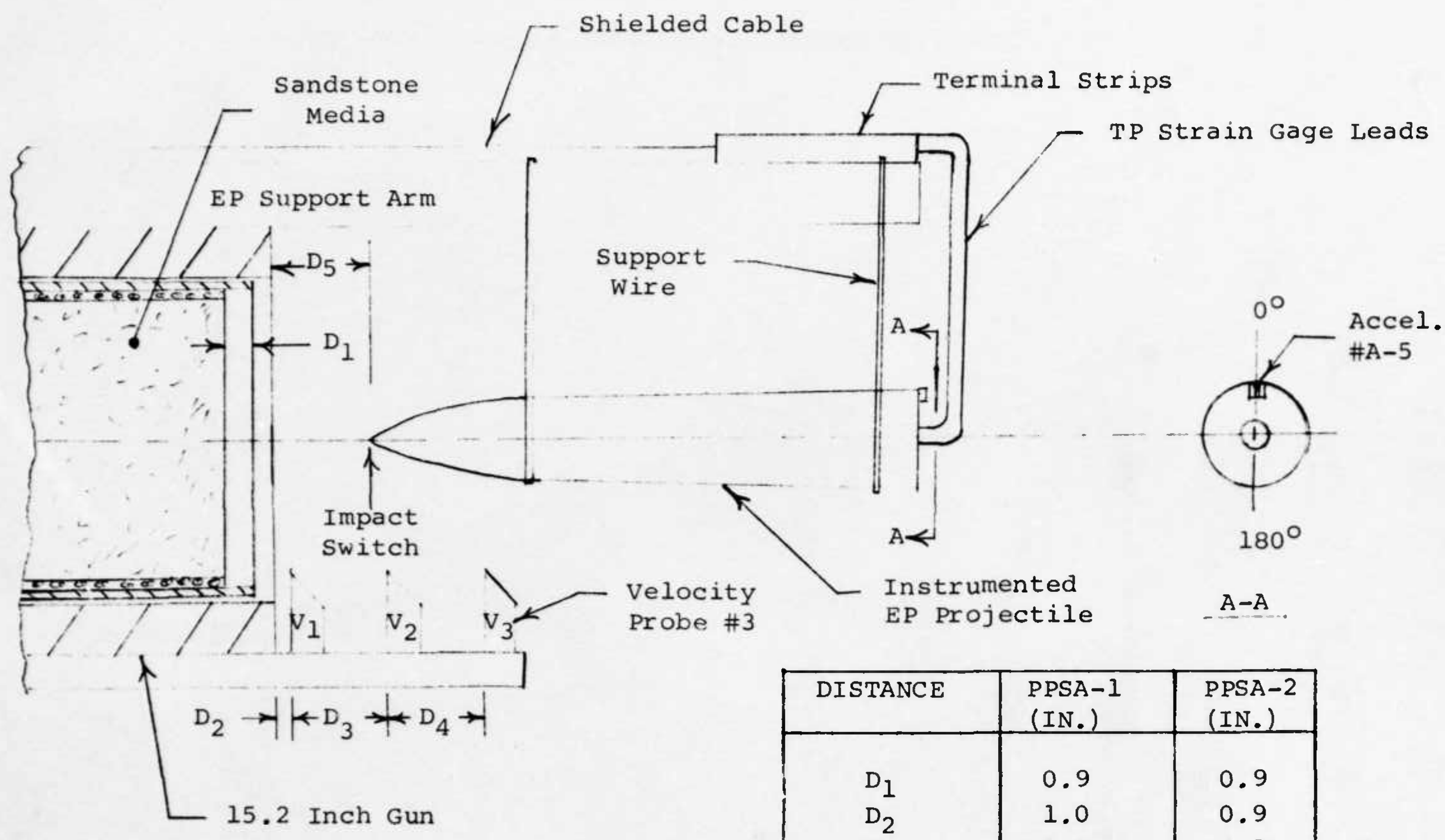
An overall view of the 15.2-inch smoothbore reverse ballistic gun facility is shown in Figure 23. Principal components include a 10 foot long barrel section and a separate recoiling breech section. Although the EP model was supported by the barrel section (as shown in Figure 24) perturbation of the model was negligible because the barrel section does not move during the duration of the impact event. This is confirmed by test films.

The following quantities were measured for the two tests:

1. Axial and hoop strain at 18 locations inside the EP and 18 locations on the outer shell (36 strain gages at 8 stations).
2. Axial acceleration and shock (5 piezoresistive accelerometers and 2 passive accelerometers).
3. Gun breech pressure (PCB piezo-electric pressure transducer).
4. Velocity of the sandstone media projectile (three make circuit switches and high speed motion picture cameras).
5. Time of impact (1 make circuit).

A schematic of the EP model is shown in Figure 20. Sensor locations are listed in Table 2 and Figure 20. The EP model was instrumented by Sandia, Albuquerque, N.M. with 36 foil strain gages (BLH FAE-06-12S6-EL1) having integral Teflon coated AWG 32 leads about four feet long. Five Endevco type 2264-50K-R piezoresistive shock accelerometers were mounted at various locations. These accelerometers have a measuring range of ±50,000 g and a

Figure 23. Test 1 — overall view of test setup for impacting EP model PPSA-1.



DISTANCE	PPSA-1 (IN.)	PPSA-2 (IN.)
D_1	0.9	0.9
D_2	1.0	0.9
D_3	6.0	6.0
D_4	6.0	6.0
D_5	10	7.15

86-2753

Figure 24. Side view of test setup for DNA PPSA tests.

useful frequency response from dc to 30 kHz. The nominal mounted resonant frequency is 180 kHz.

Because of the large number of data channels required, two 14-track magnetic tape recorders were used. All strain and accelerometer data were recorded on an Ampex FR-1800H recorder, while velocity, impact time and gun breech pressure were recorded on an Ampex DAS-100 system (FR-1300).

The FR-1800H recorder has 14 tracks of direct record capability having a frequency response of 400 Hz to 1500 kHz. Forty FM record channels were frequency multiplexed onto the first eight tracks of the FR-1800H recorder. Each strain gage signal (resistance variations converted to proportional voltage changes) modulated a voltage controlled oscillator (VCO) to provide a deviation of the center carrier frequency proportional to the amplitude of the signal. The outputs of five VCO's were combined to form a composite FM multiplex suitable for recording five channels of strain data onto one track of the magnetic tape recorder. The multiplexed signal, when reproduced from the tape recorder, is passed through an FM Demultiplex System which separates the various carriers, demodulates the selected channels, amplifies and shapes the resultant output so that it accurately reproduces the original signal. The bandwidth of each data channel is determined primarily by the reproduce filter bandwidth of the demodulator.

A dc to 32 kHz (3dB) bandwidth having a signal-to-noise (S/N) ratio better than 35 dB is available. This bandwidth can be reduced to 20 kHz to increase the S/N ratio if the data frequency permits. Both constant amplitude and linear phase filters are available to faithfully reproduce complex as well as sinusoidal type signals.

Twenty multiplexed channels accept low level analog voltages. Ranges of ±5 mV P-P to 10 volt P-P are switch selectable. The remaining 20 channels accept inputs from 500 mV P-P to 2 volts P-P. These units require pre-amplification of the low millivolt strain signals. Preston type 8300 XWB and Neff type 110A differential floating input amplifiers having a 3 dB bandwidth of dc to 100 kHz were used for signal amplification. Strain gage data signal lines, and the conditioning unit, were designed to provide a bandwidth commensurate with the record/reproduce capabilities.

A block diagram of the strain and acceleration data acquistion system is shown in Figure 25. Typical strain and accelerometer channels are shown in Figures 26 and 27. The scheme for reproducing data is shown in Figure 28.

The typical resultant system bandwidth from input to output was measured and is provided in Figures 29 through 34.

Accelerometer outputs were transmitted directly into a wideband VCO having a dc to 500 kHz record bandwidth. Line equalization was provided in the VCO input to broaden the frequency response capabilities of the data lines. The high impedance of the accelerometers and line reactance combined to reduce the 3 dB bandwidth to about 15 kHz. Line equalization increased bandwidth to about 25 kHz. The equalized system end to end response for a typical accelerometer channel is shown in Figure 34. Accelerometer data presented in this report was reproduced via a 32 kHz filter to reduce high frequency noise and accelerometer ringing.

Gun breech pressure, make circuit outputs for velocity and impact and an IRIG time base were recorded on a DAS-100 (FR 1300) magnetic tape recorder having a record/reproduce bandwidth of dc to 20 kHz.

The entire data acquisition system, with the exception of the conditioning unit and connecting cables, was contained and controlled from an instrumentation van located approximately 150 feet from the reverse ballistic gun. The van (Figure 35) was protected from shock and debris by an earth berm.

Photographic coverage provided high resolution position-time data for the target and media projectiles. Camera positions are shown in Figure 36. A Hi-Cam high speed motion picture camera (16,000 fps, 8mm) was positioned normal to the trajectory centerline to record P-2 position-time data. A high speed shutter was used to provide a sharp object image. The target and media projectiles were back-lighted using a reflector and an array of FF-33 long duration flash bulbs. A sequencer synchronized camera operation, flash bulb triggering and gun firing.

Additionally, a Fastax high speed motion picture camera (5,000 fps, 16mm) was employed to observe the impact event. A Milliken high speed framing camera (400 fps, 16mm) was used to observe the overall test event.

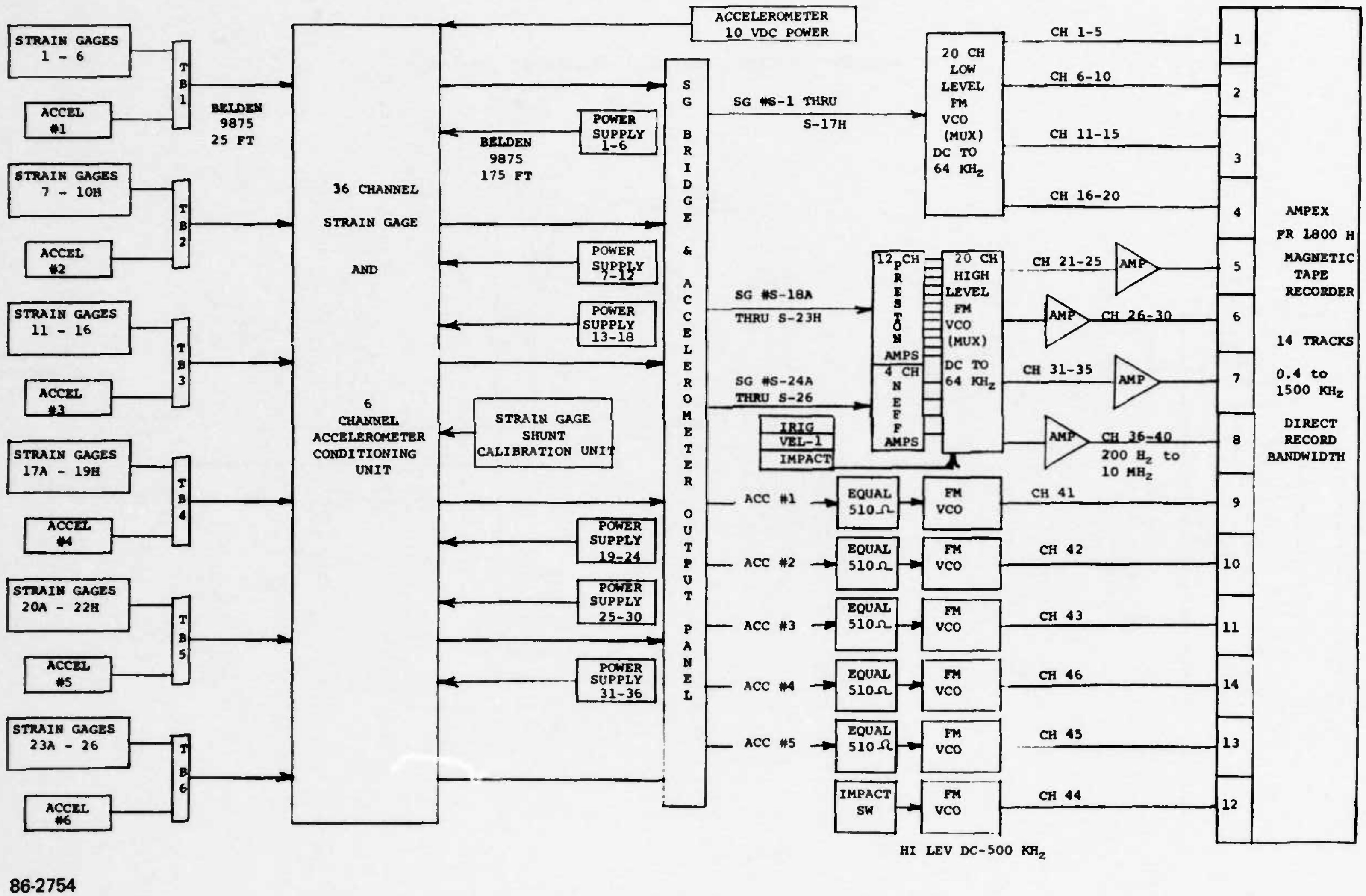
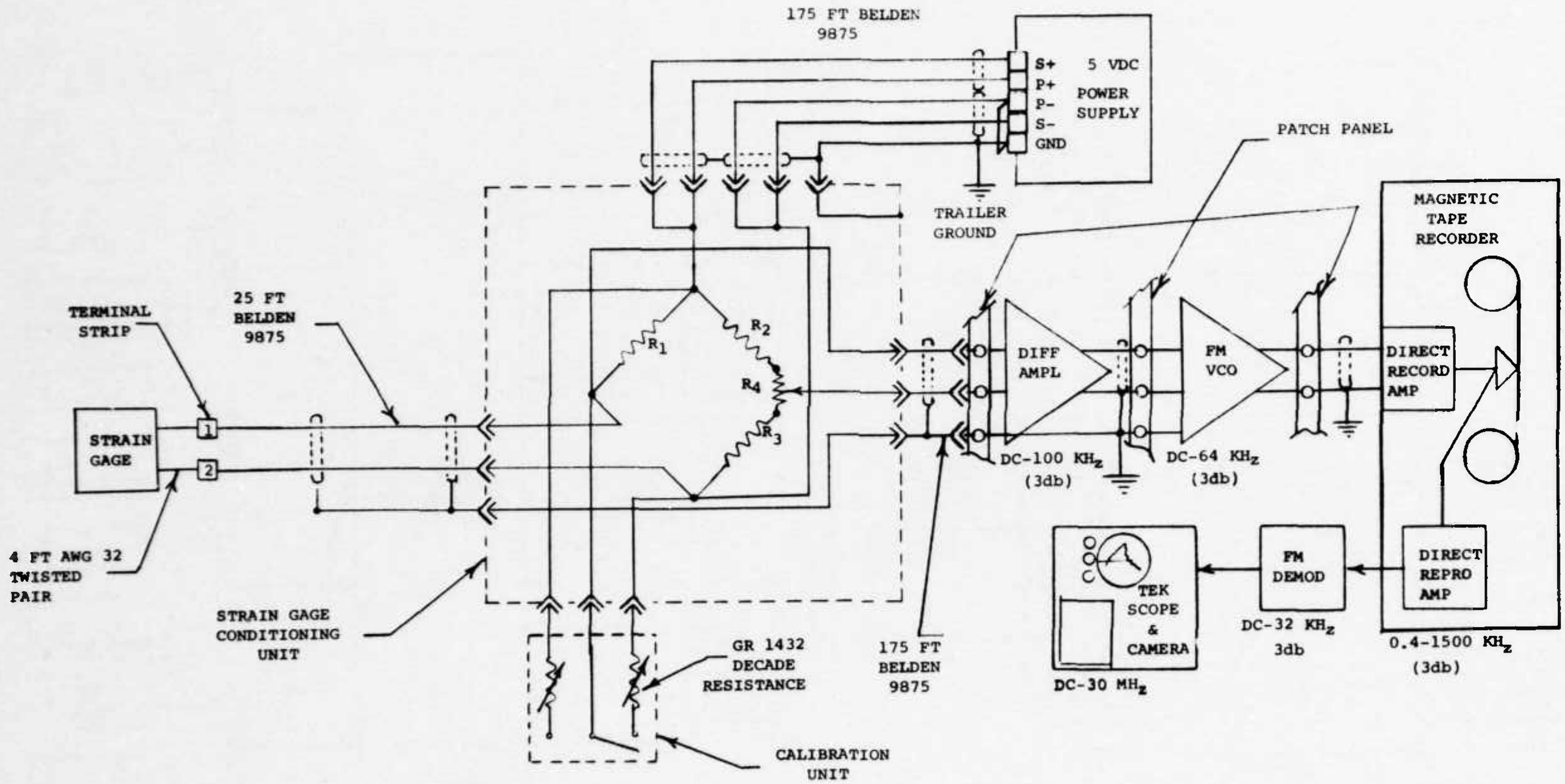
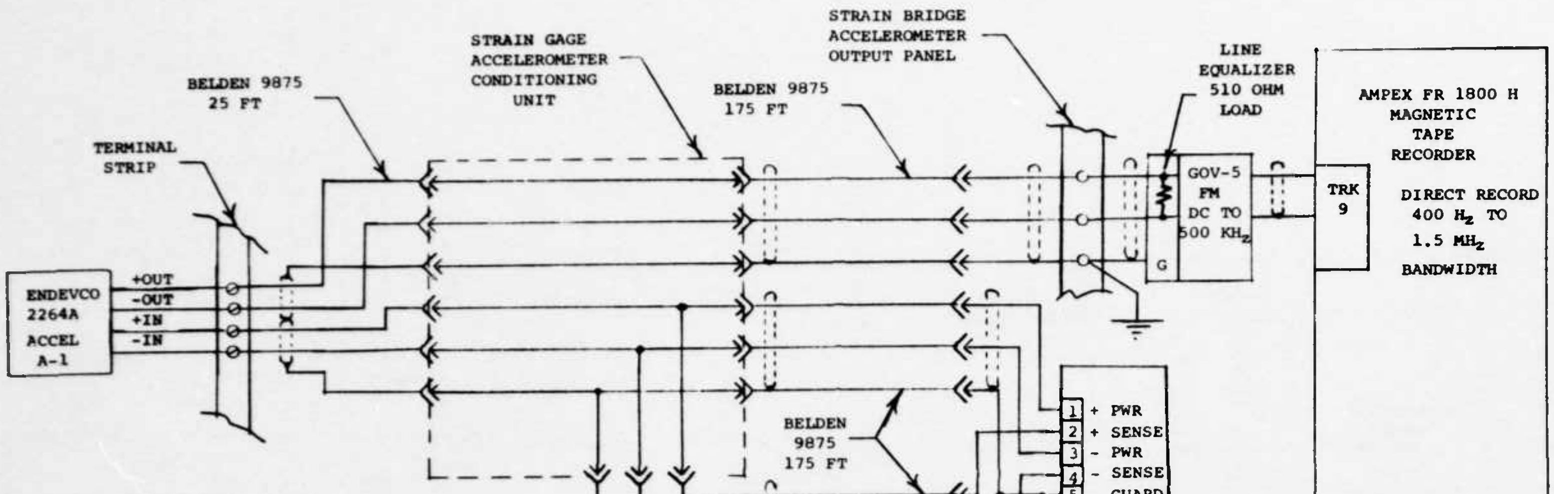


Figure 25. Reverse ballistic strain/acceleration signal transmission/acquisition.



86-2755

Figure 26. Typical strain gage channel electrical schematic.



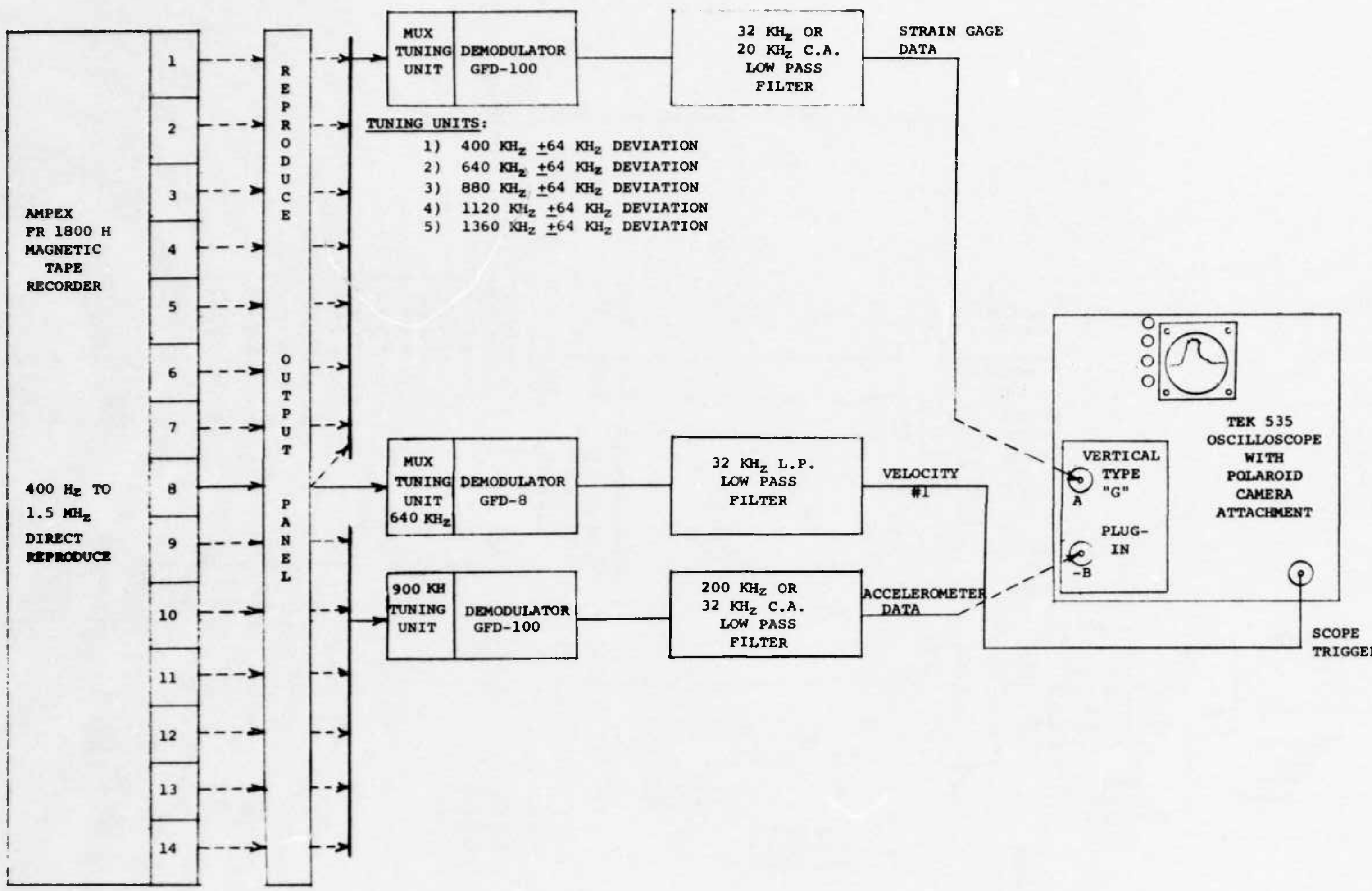
SENSITIVITY ADJUSTMENT DUE TO OUTPUT LOADING:

$$E_{OL} = \frac{E_O R_L}{R_O + R_L}$$

Where: R_O = Accelerometer Output Resistance.
R_L = Load Resistance.
E_O = Non-Loaded output.
E_{OL} = Loaded output.

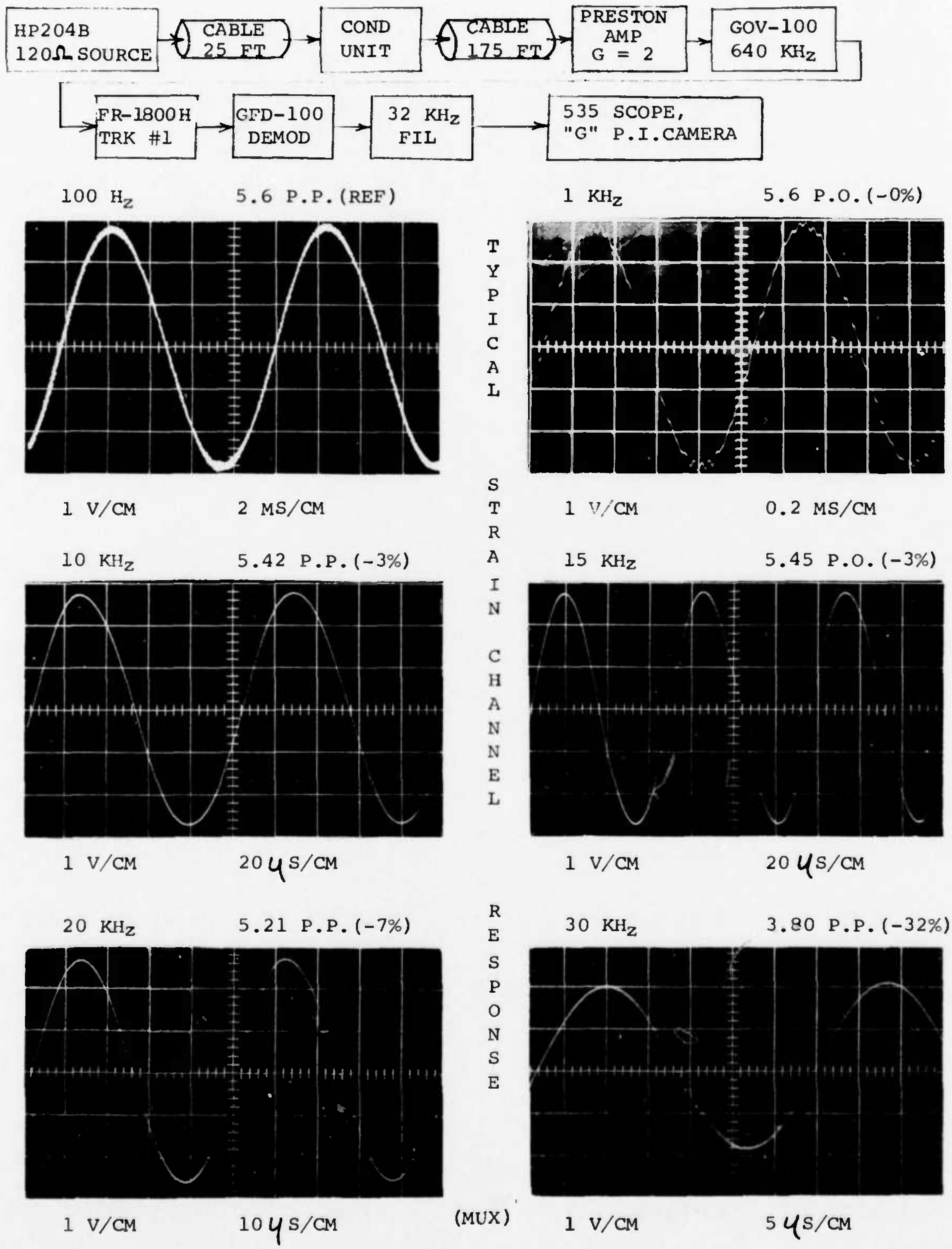
86-2756

Figure 27. Typical accelerometer channel electrical circuit.



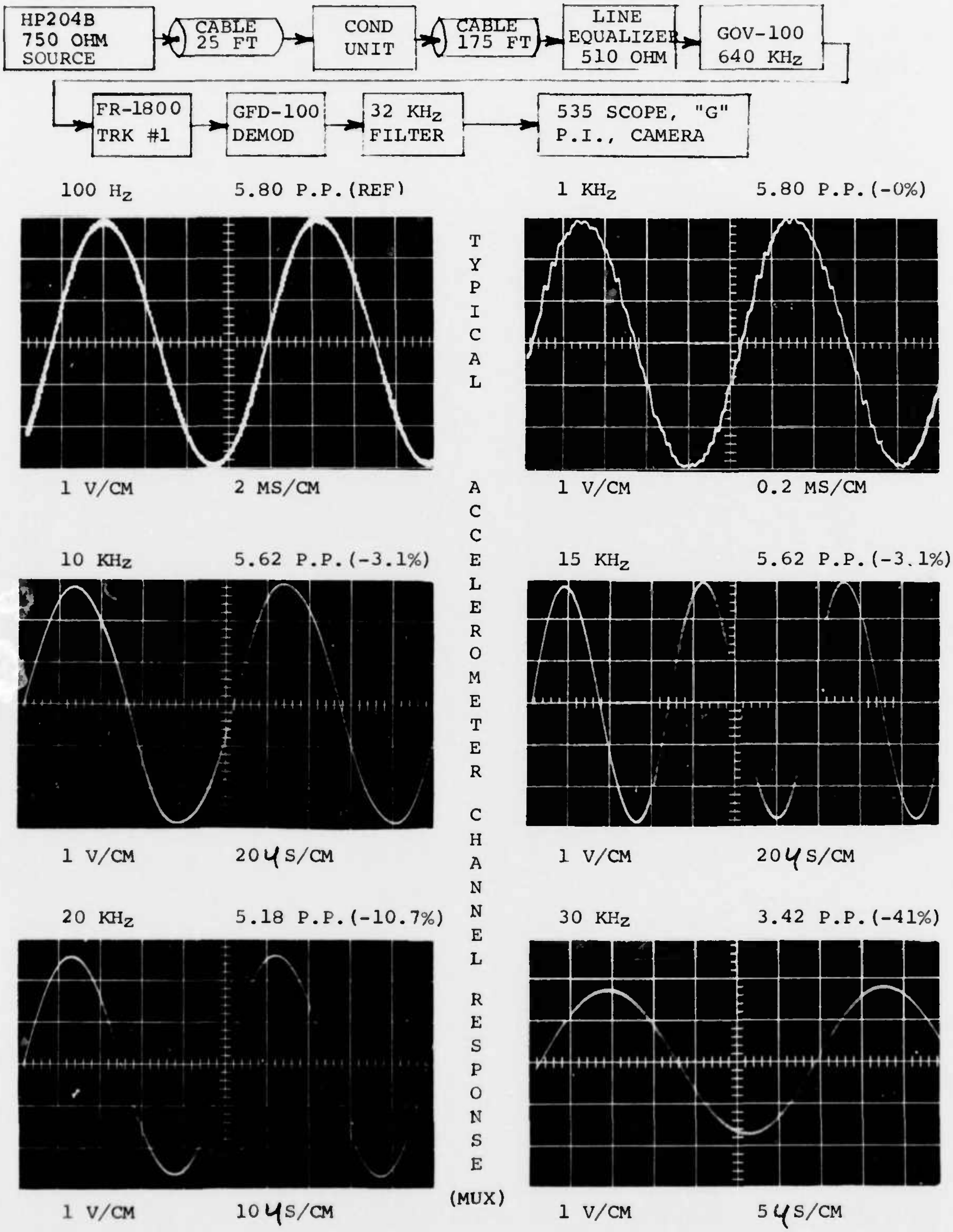
86-2757

Figure 28. Reverse ballistic strain gage/accelerometer/signal playback from magnetic tape.



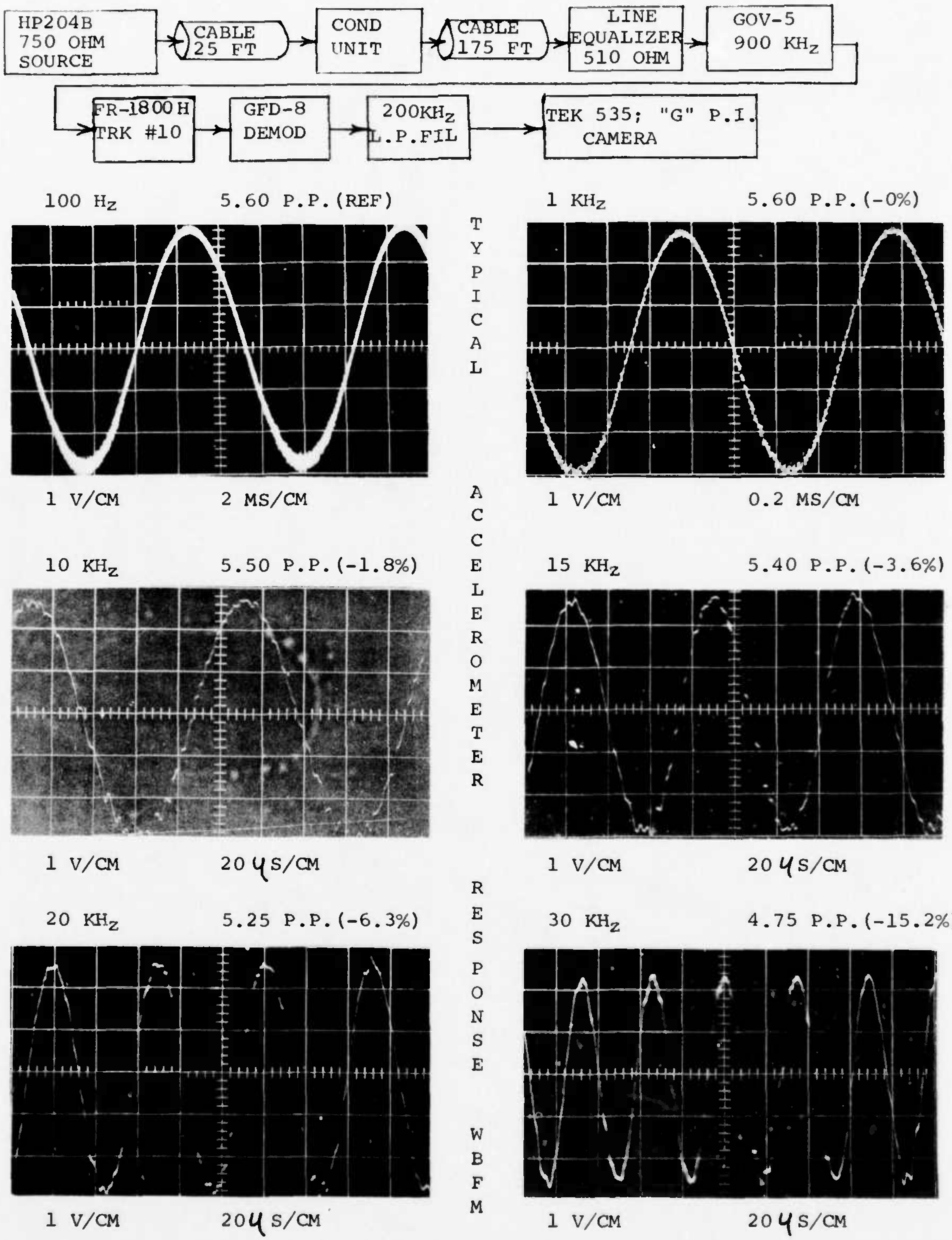
86-2758

Figure 29. End to end system response — accelerometer 1 line with 120 ohm source impedance.



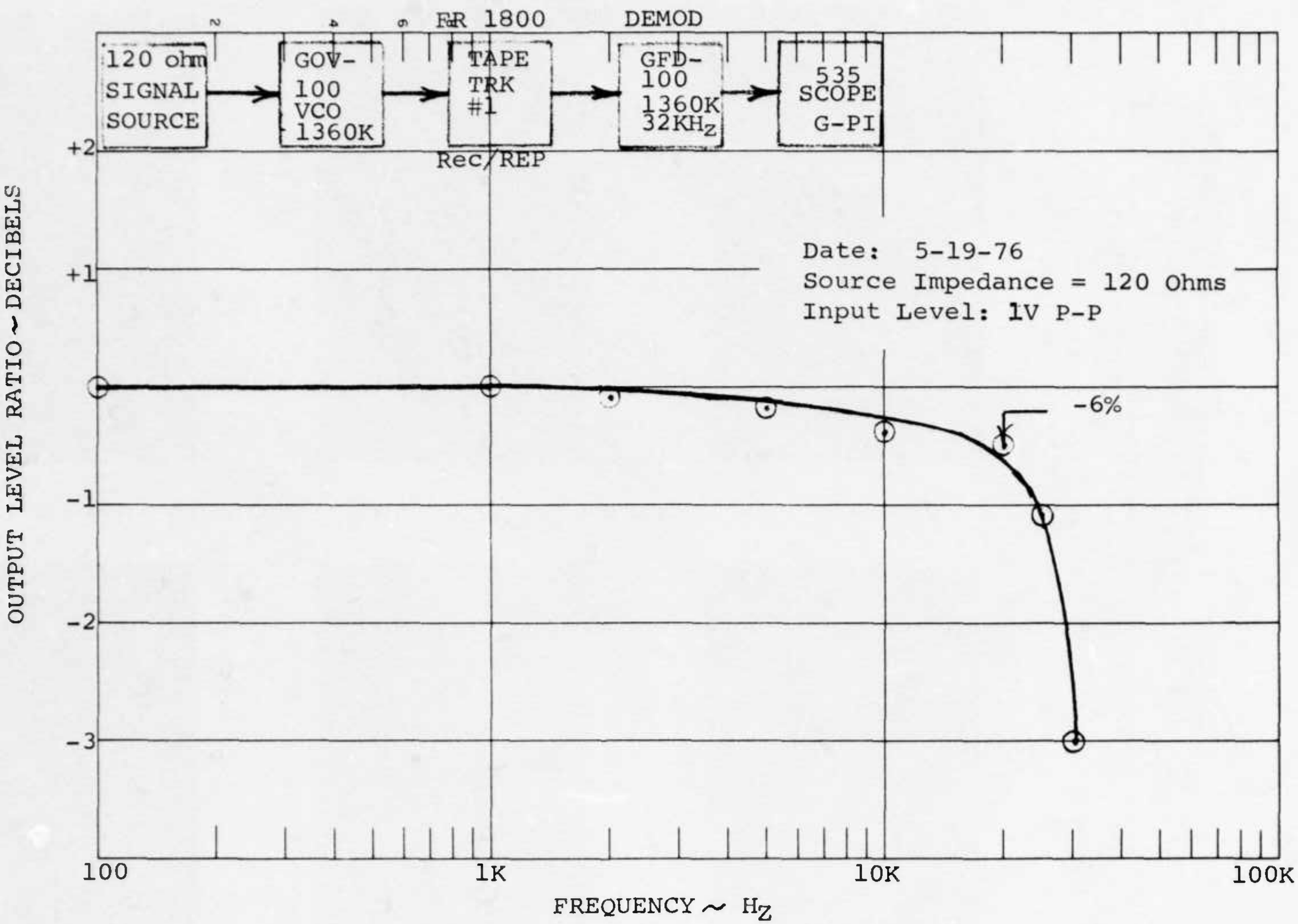
86-2759

Figure 30. End to end system response – accelerometer 1 line with 750 ohm source and equalized line (51 ohm load).



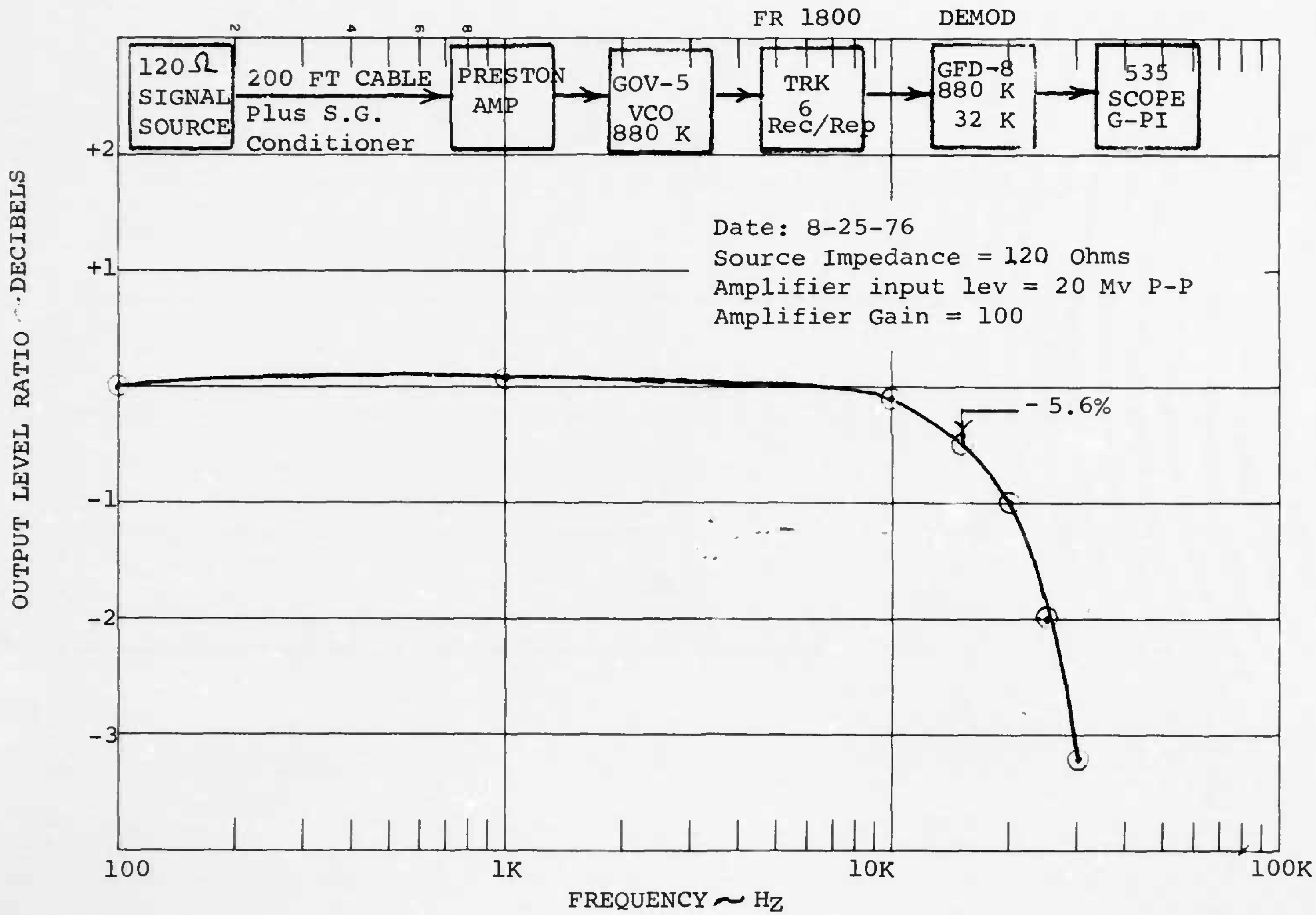
86-2760

Figure 31. End to end equalized (510 ohm) response – accelerometer 2 line into WBFM Track 10 (200 kHz BW).



86-2761

Figure 32. End to end record/reproduce response for strain gage channel 5.



86-2762

Figure 33. End to end record/reproduce response for strain gage Channel 28 (S.G. 21H).

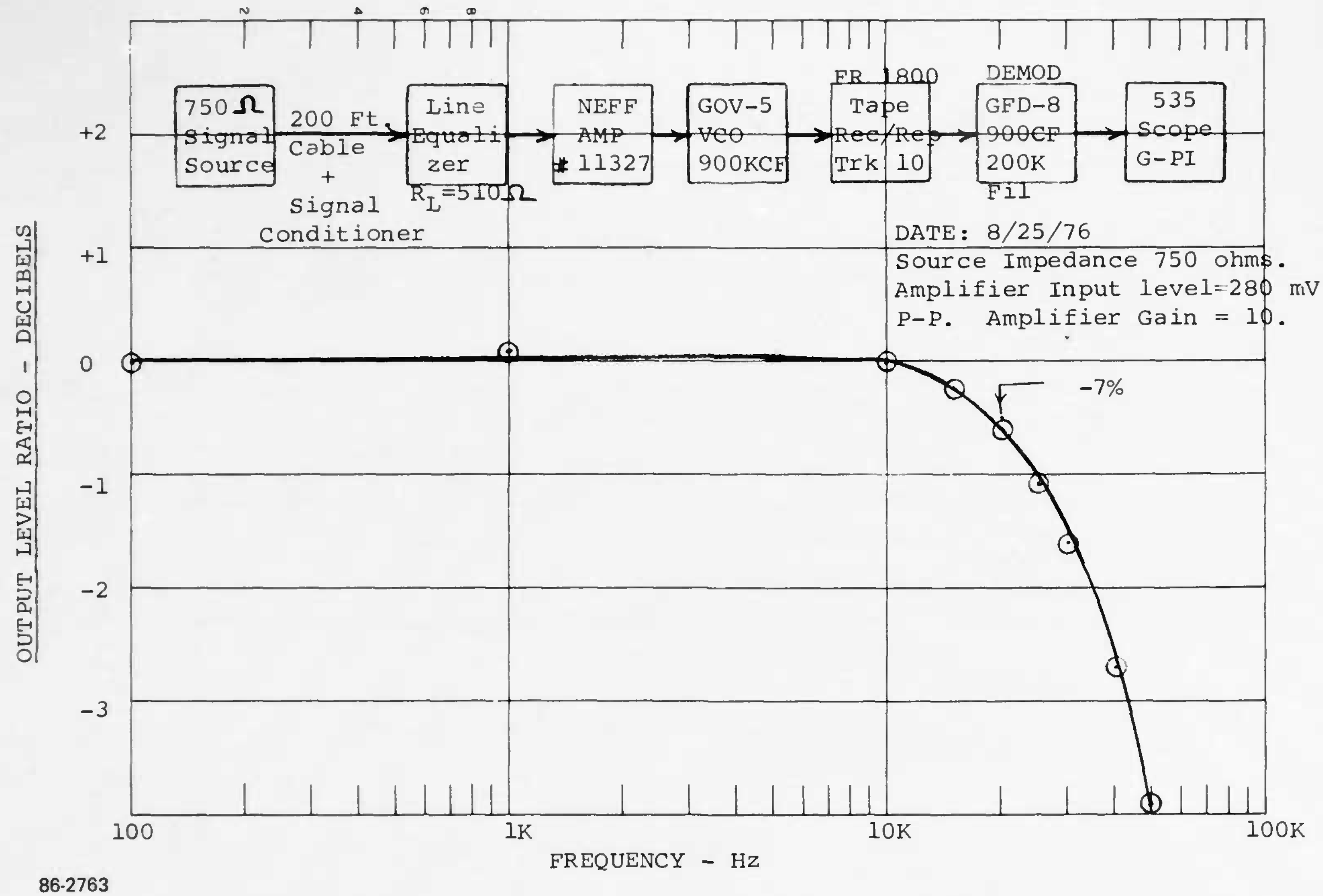


Figure 34. End to end record/reproduce response for accelerometer Channel 2.

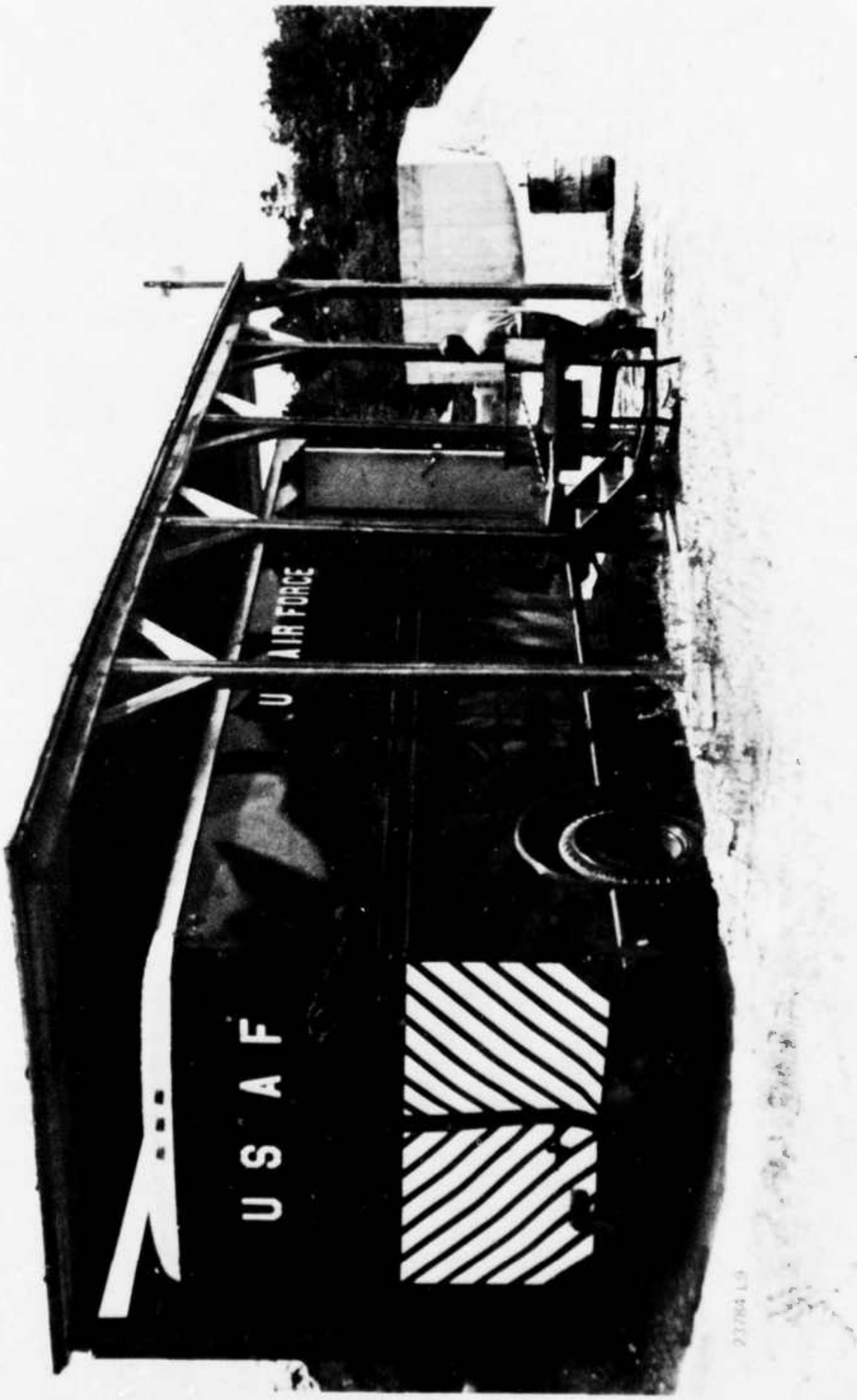


Figure 35. Instrumentation ban.

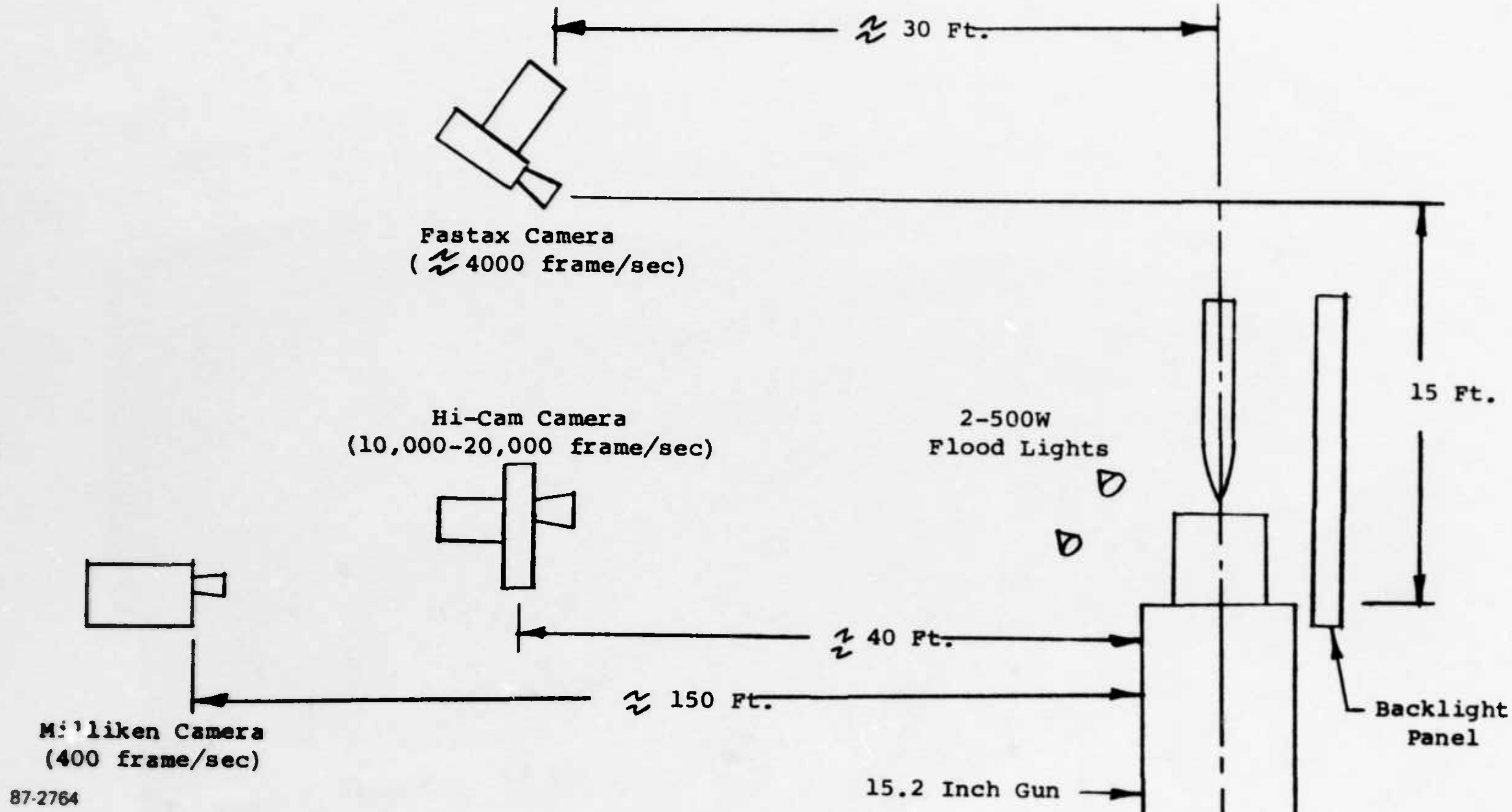


Figure 36. Schematic of camera positions.

Test Procedure

A schematic of the test setup is shown in Figure 24. The EP model was suspended from an expendable wooden support by two rubber covered AWG 18 wires. Yaw and lateral sway was prevented by additional wires between the EP and other wooden projections attached to the bottom of the gun barrel. (See Figure 37.) The model was aligned with the gun centerline to obtain less than ±1/4 degree alignment error. Lateral alignment was accomplished using a straight edge and vertical alignment by a precision gunners quadrant.

Velocity probes (three normally open make switches) were attached to a steel beam clamped to the barrel. A thin foil contact switch was taped to the EP model nose to provide an impact event signal.

Instrumentation leads from the EP projectile were connected to a barrier terminal trip attached to the wooden EP support arm. Shielded twisted pair wires, contained in a multipair cable about 25-feet long, completed the connection between strain gages/accelerometers and the signal conditioning unit.

After loading the media projectile in the gun, the data acquisition system was checked to determine proper operation. Strain and acceleration ranges were set as shown in Table 2. Strain gage bridges were balanced for zero voltage output. Simulated compression strain calibration signals were generated and recorded by shunting known resistances across each strain gage.

The following steps were included in the final countdown and firing sequence.

1. Check firing line for continuity.
2. Turn on tape recorder and verify proper operation.
3. Connect firing line to sequencer box.
4. Start high speed motion picture cameras.
5. When the primary camera is at the proper speed a camera operated switch completes a circuit in the sequencer box to start a timer and apply power to flash bulbs. After a preset timer delay, to allow the flash bulbs to reach peak illumination, the sequencer automatically fires the gun.

Following the test, the catcher was disassembled to recover the EP model. Strain and accelerometer data was reproduced on site by playback into an oscilloscope equipped with a Polaroid camera.

Figure 37. Test 2 -- model PPSA-2 support and velocity probes.

Test Results and Discussion

Test results are summarized in Tables 3 through 7.

The first test (Model PPSA-1) was conducted at a normal impact, i.e., the media projectile centerline and trajectory was coincident with the longitudinal axis of the EP. The sandstone media projectile velocity was measured to be 1927 ft/s by both electrical circuits and film data. Analysis of the film data indicated that the sandstone integrity was maintained up to the time of impact. The EP penetrated the sandstone and aluminum base with no observed change in its angle of attack. Plots describing motion of the media projectile and the EP model base are shown in Figures 38 and 39, respectively. A post test photograph of the PPSA-1 model is shown in Figure 40. Final position of the EP model indicated penetration into less than four feet of sand. (See Figure 41.) Gun breech pressure for this test was measured to be 13,500 lb/in^2 peak.

TABLE 3. TEST SUMMARY

	Test 1	Test 2	Predicted
Impact velocity (ft/s)	1927	1766	1800
Strain gage reliability	95%	95%	
Avg axial strain, $k\mu\epsilon$	3.2	2.7	2.3
Accelerometer reliability	60%	60%	
Avg axial acceleration, kg	12.8	12.0	12.2

Propellant was loaded into the gun and the gun was prepared for firing.

The second test (Model PPSA-2) was also conducted at a normal impact attitude. The sandstone media projectile velocity was measured to be 1760 ft/s by film data (redundant cameras). No electrical velocity or breech pressure data was obtained due to malfunction of the DAS-100 tape recorder. Film analysis again showed that the sandstone media maintained its integrity and that there was no observable buildup in the angle of attack. Plots describing motion of

TABLE 4. EVENTS – TEST 1

Impact to contact Al can base	0.433 ms
Impact to envelopment sta 4	0.173 ms
Impact to envelopment sta 9	0.350 ms
Impact to envelopment sta 19.5	0.846 ms
Impact to envelopment sta 32	1.666 ms

TABLE 5. COMPARISON OF STRAIN DATA – AXIAL

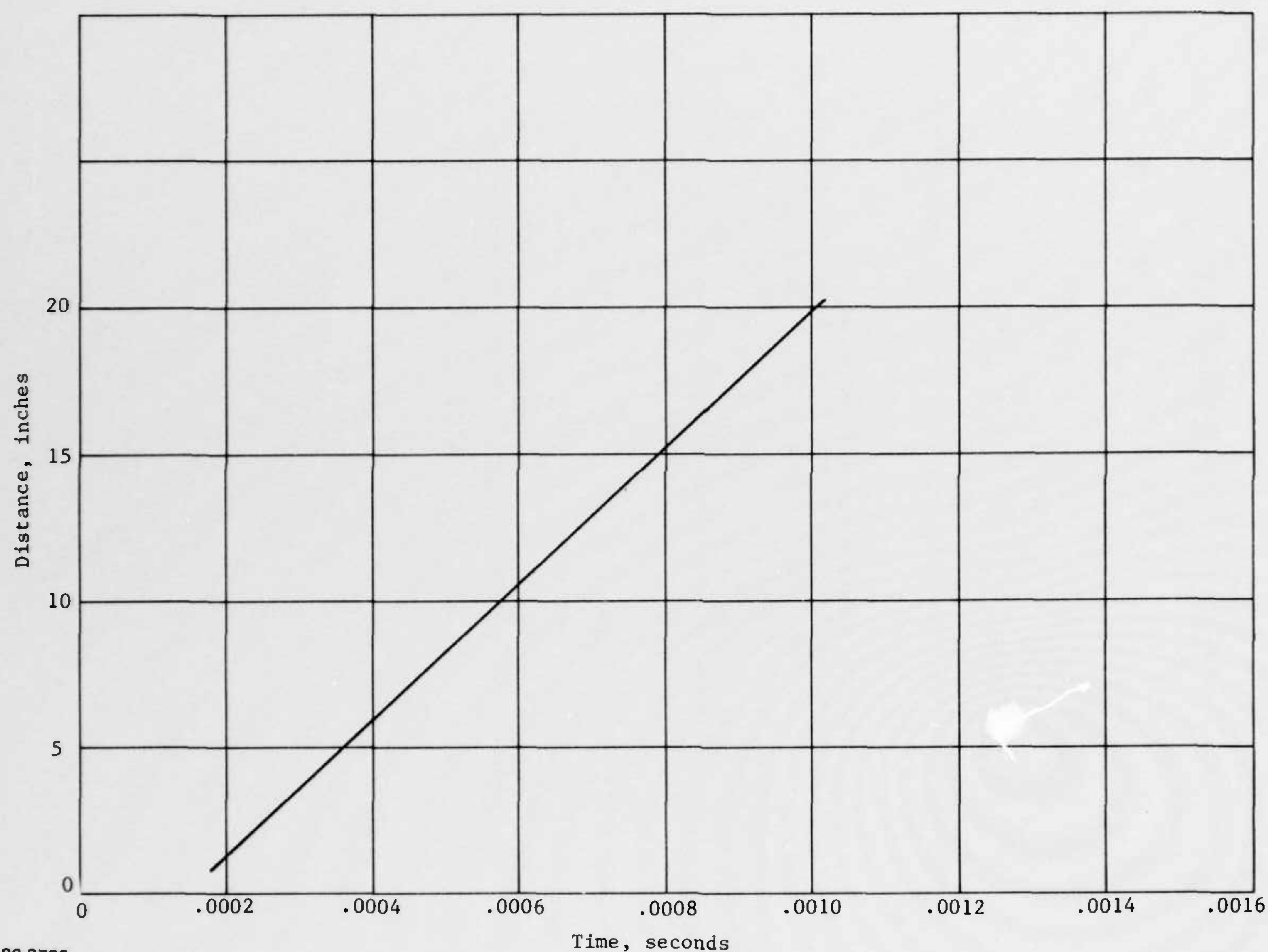
Station	Location	Peak avg axial K_ϵ test 1	Peak avg axial K_ϵ test 2	Peak predicted K_ϵ
9.0	ID can	-5.8	-6.2	-4.8
12.0	Payload	-1.9	-1.8	-1.4
16.0	OD pot	-8.1	-5.2	-5.2
19.5	ID can	-5.5	-5.2	-6.3
26.25	Payload	-1.6	-1.0	-1.1
27.3	ID payload	-0.3	-0.3	-0.4
31.5	ID can	?	?	-0.06
4.0	OD shell	-2.2	-2.4	-2.3
9.0	OD shell	-2.3	-2.2	-2.0
19.5	OD shell	-1.8	-1.7	-1.6
27.3	OD shell	-1.0	-1.0	-0.9

TABLE 6. COMPARISON OF STRAIN DATA – HOOP

Station	Location	Peak avg hoop $k\epsilon$ test 1	Peak avg axial $k\epsilon$ test 2	Peak predicted $k\epsilon$
19.5	ID can	+0.8	+1.2	+1.2
4.0	OD shell	+0.8	+1.0	N/A
9.0	OD shell	+0.7	+0.6	+0.6
19.5	OD shell	+0.6	+0.7	+0.5

TABLE 7. COMPARISON OF ACCELEROMETER DATA

Station	Peak axial accel. test 1 kg	Peak axial accel. test 2 kg	Peak axial predicted accel. kg
7.2	10	--	12
14.75	--	11	12
19.5	13.5	9	9
27.8	--	16	12
32.0	15	--	16



86-2766

Figure 38. P2-1 projectile velocity.

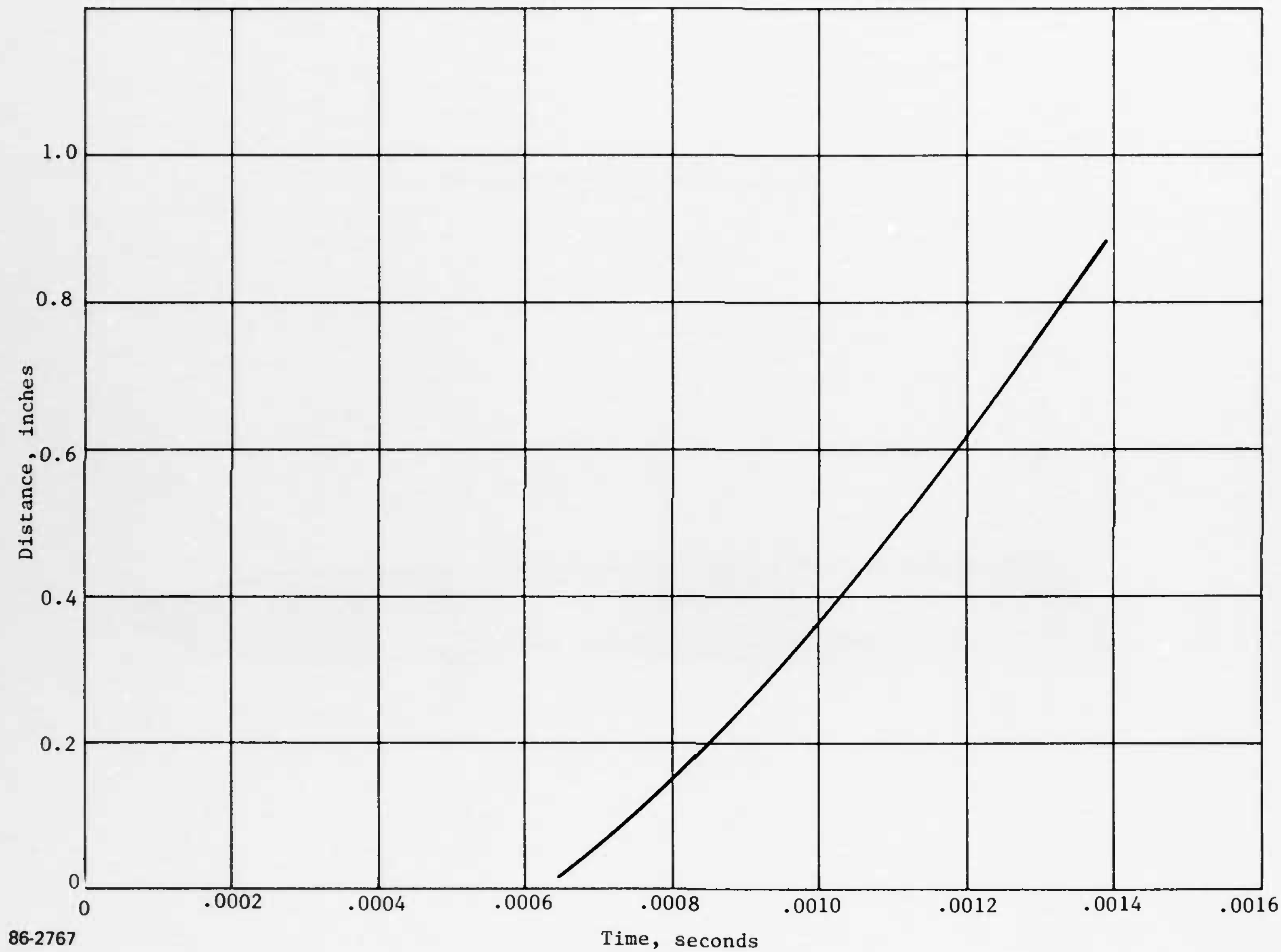


Figure 39. P2-1, Responding movement of target vehicle to projectile.

86-2768

Figure 40. Model PPS-1 – post test condition.

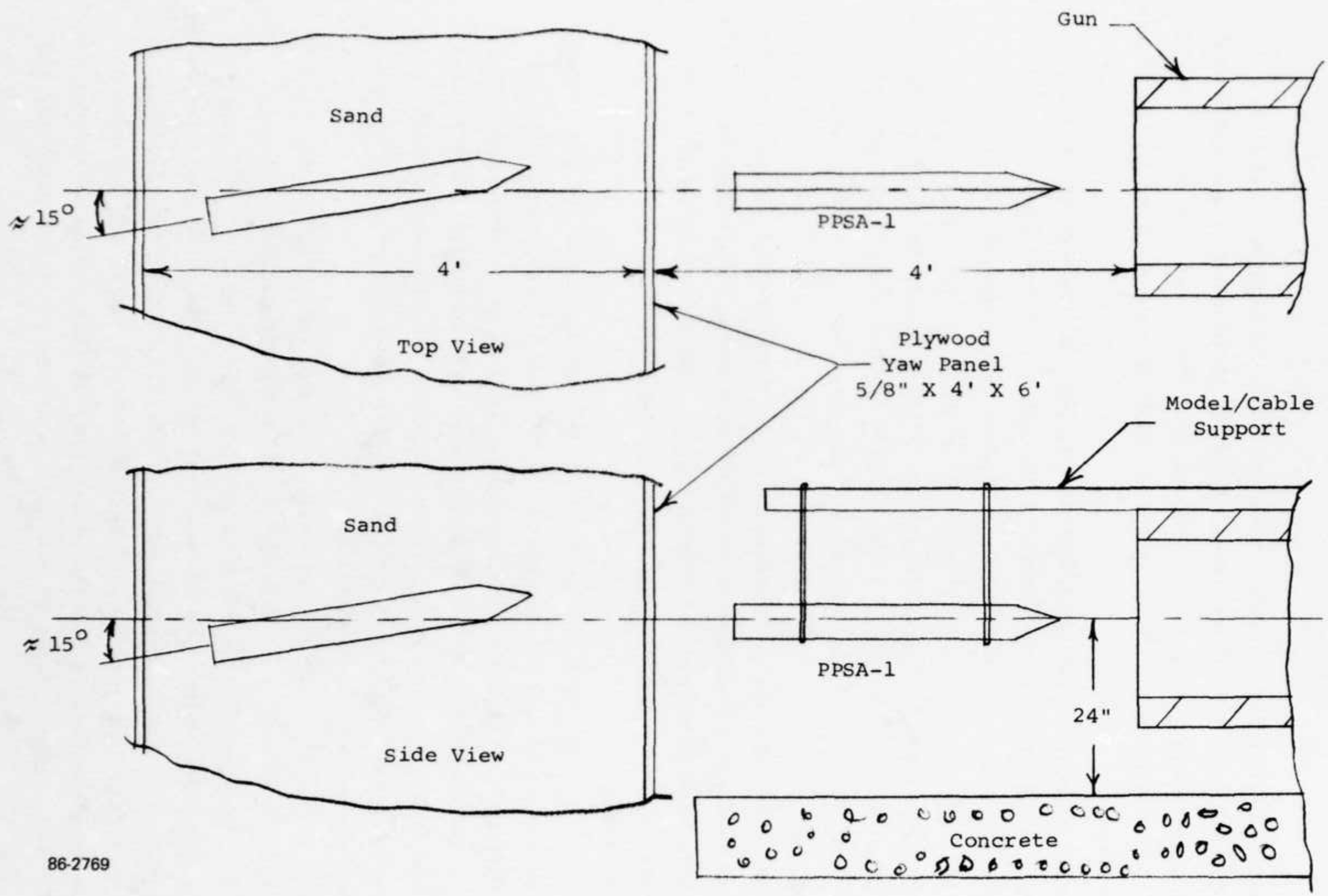


Figure 41. Test 1 -- PPSA-1 model post test final position.

the media projectile and EP model base are shown in Figures 42 and 43 respectively. Post test photographs of the EP model catcher and media projectile base are shown in Figures 44 through 47. Final position of the EP model indicated penetration into less than four feet of sand as shown in the Figure 48 schematic.

Strain gage, accelerometer, breech pressure and electrical velocity data for test 1 are presented in Figures 49 through 59. Strain gage and accelerometer data for test 2 are presented in Figures 60 through 70. Additional photographs of the two tests are shown in Figures 71 and 72.

Strain data was recovered from 68 of 72 gages installed (95%). Three strain gages (18H and 20A Test 1 and 11 Test 2) were shorted before test, probably due to shorted lead wires, and one (18H Test 2) produced no sensible response.

Reasonable data was recorded for 6 of 10 accelerometers installed. Malfunctioning of one accelerometer conditioning channel resulted in failure to obtain data from accelerometer A-4 of Test 1. The others (A-2 Test 1, A-1 Test 2 and A-5 Test 2) apparently failed at impact and did not respond in a sensible manner.

In general, the quality of data obtained was excellent for this type of test. Frequency response (see Figures 32 through 35) was essentially flat to approximately 10 kHz and down approximately 3 dB at 30 kHz. Observed strain and accelerometer response frequencies were in general substantially lower than full bandwidth (i.e., approximately 6 kHz or lower). Data, therefore, was well within the system response limits wherein signal amplitude and phase are accurately reproduced.

Basic FM noise level was typically 2 percent rms or 8 percent (P-P) of band edge. (See Table 3.) In some cases transients induced relatively minor noise like responses 200 to 400 microseconds before impact (i.e., gage S-6, Test 1). This is believed to be caused by thermal and mechanical effects of the pressure wave preceeding the media projectile on the small (0.008-inch diameter) strain gage leads, or electrical effects due to gas ionization.

The data obtained is credible for a limited time period as indicated in Table 4. For example, gages on the outside at Station 4 get enveloped and

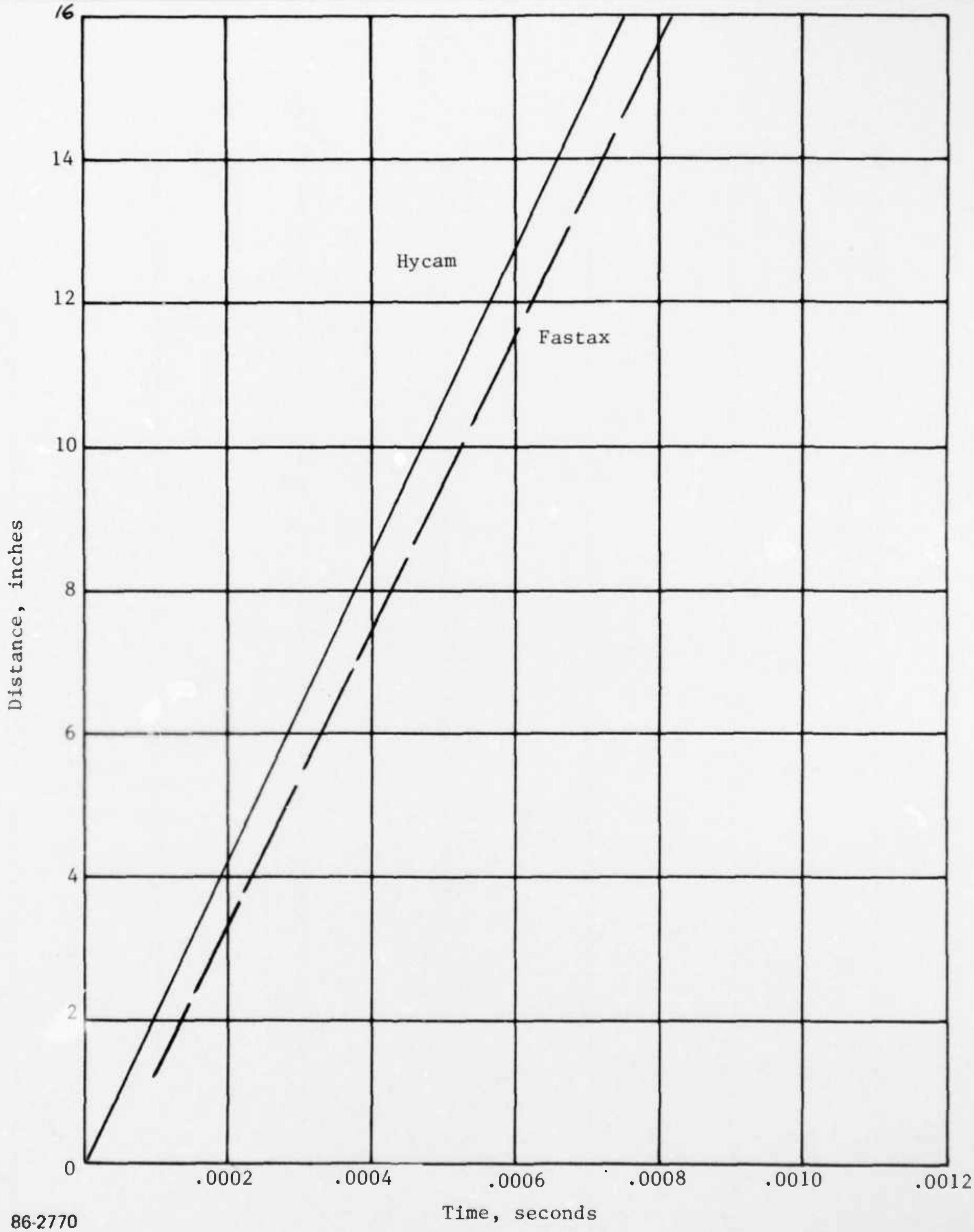
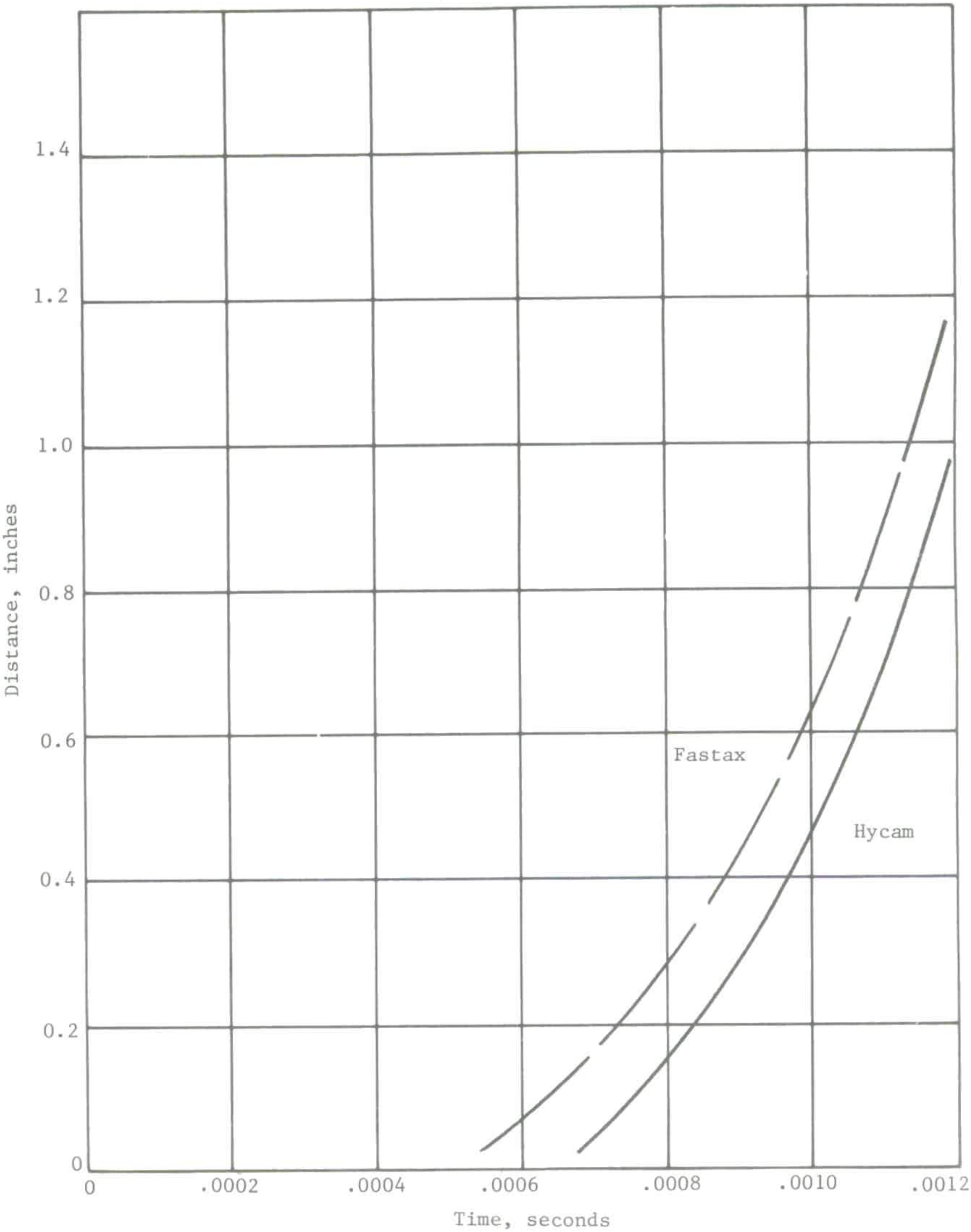


Figure 42. P2–2 projectile velocity.



86-2771

Figure 43. P2—2, responding movement of target vehicle to projectile.

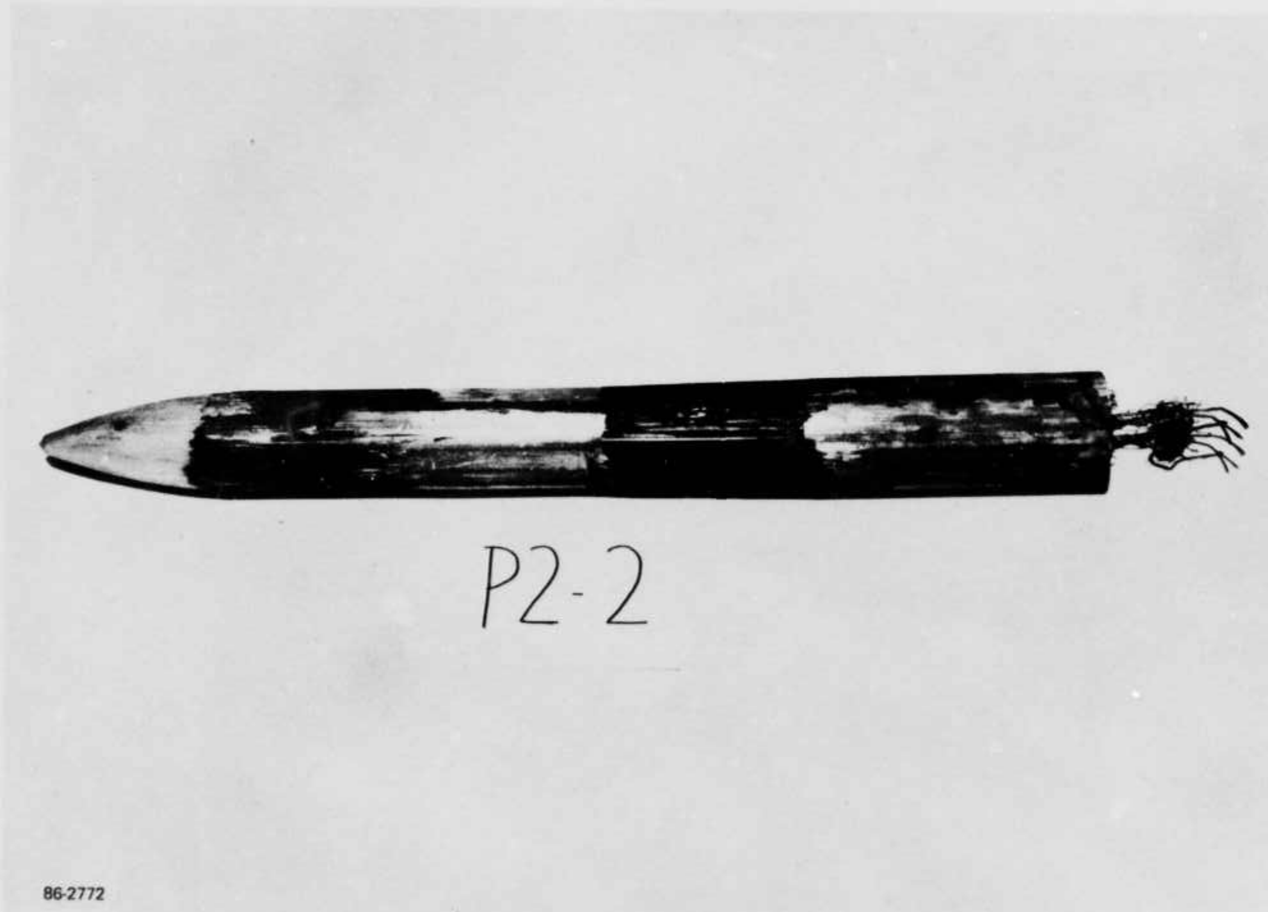


Figure 44. Model PPSA–2 -- post test condition.

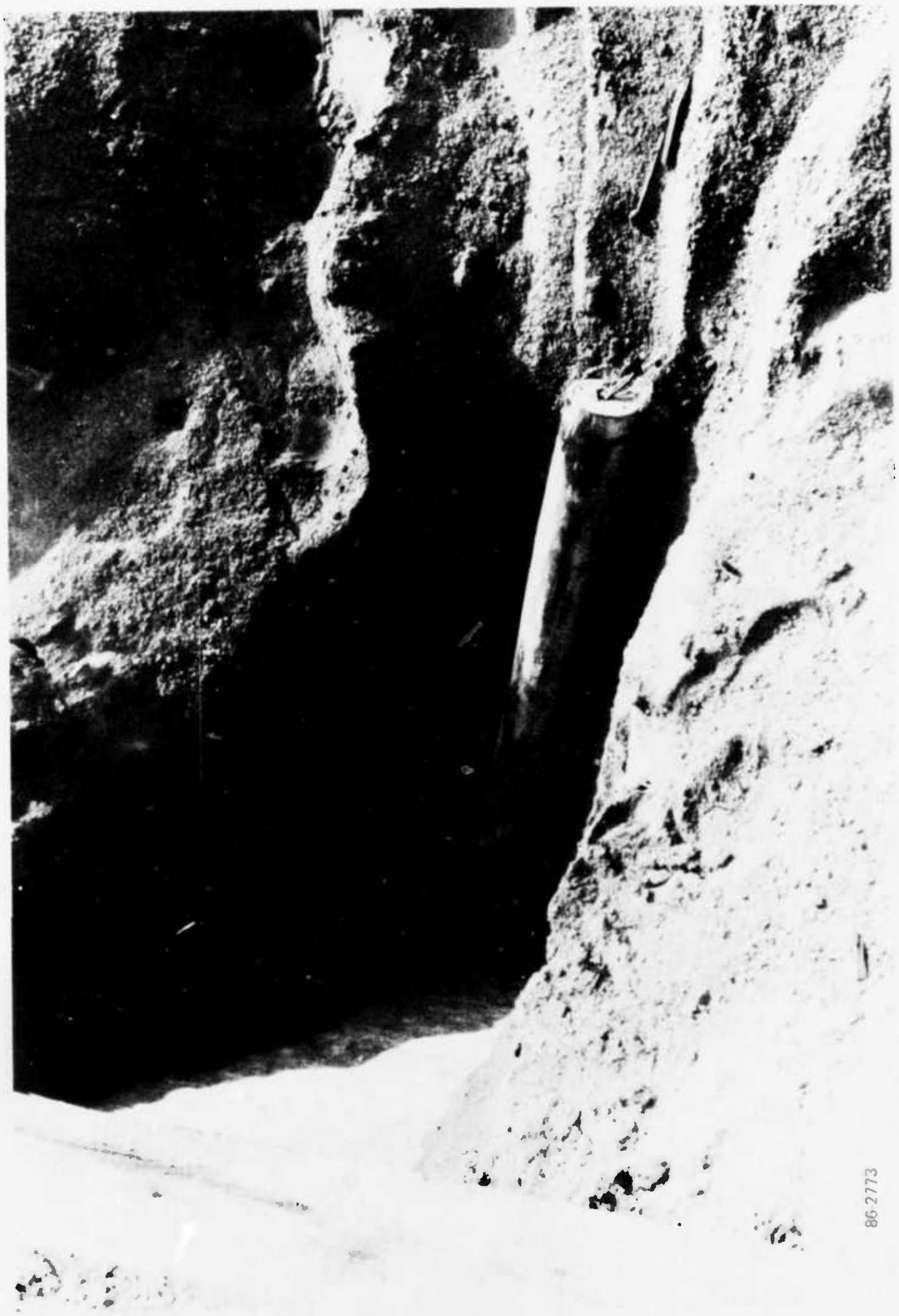


Figure 45. Test 2 -- model PPSA-2 post test position in sand.

86 2773

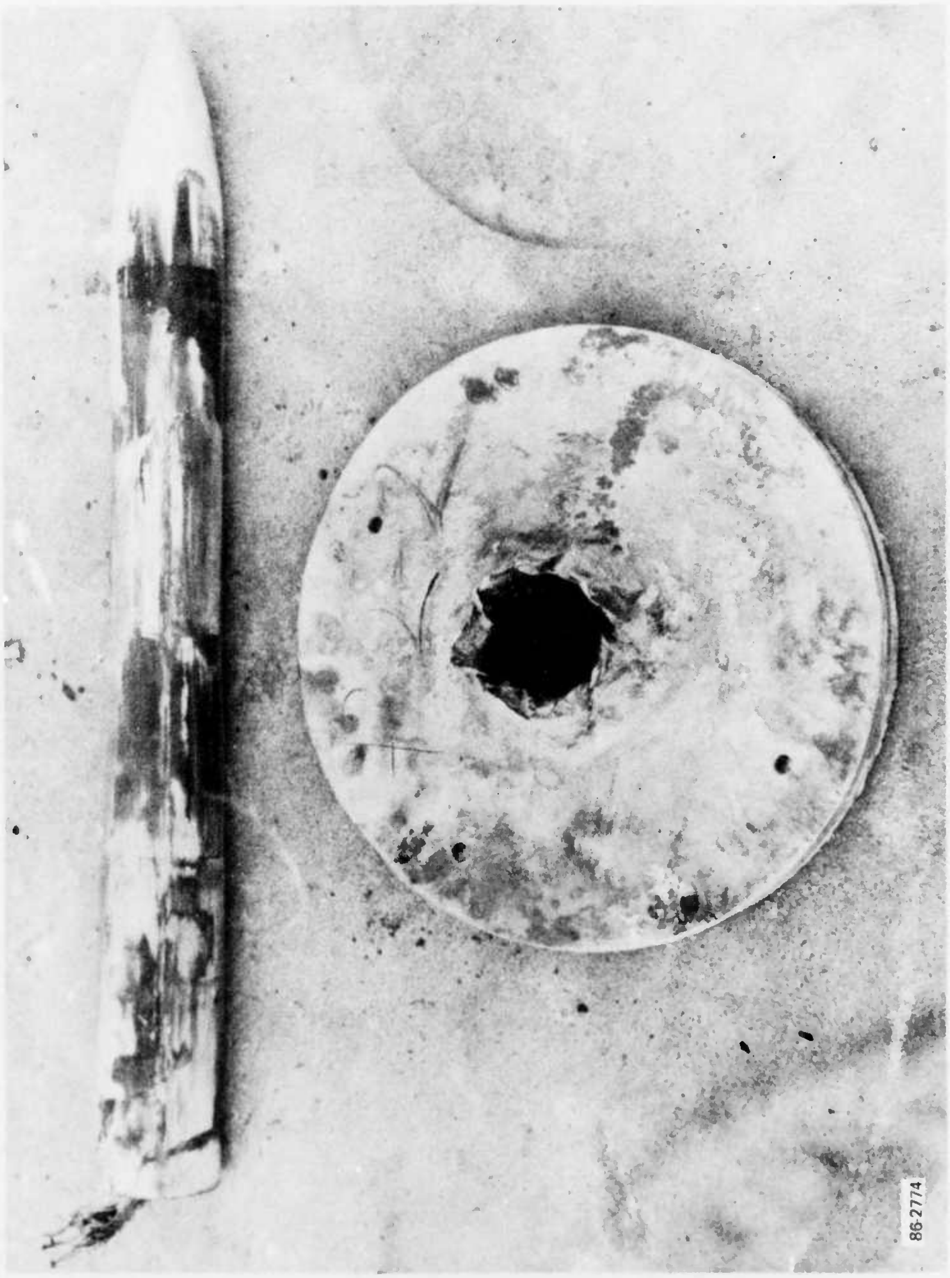
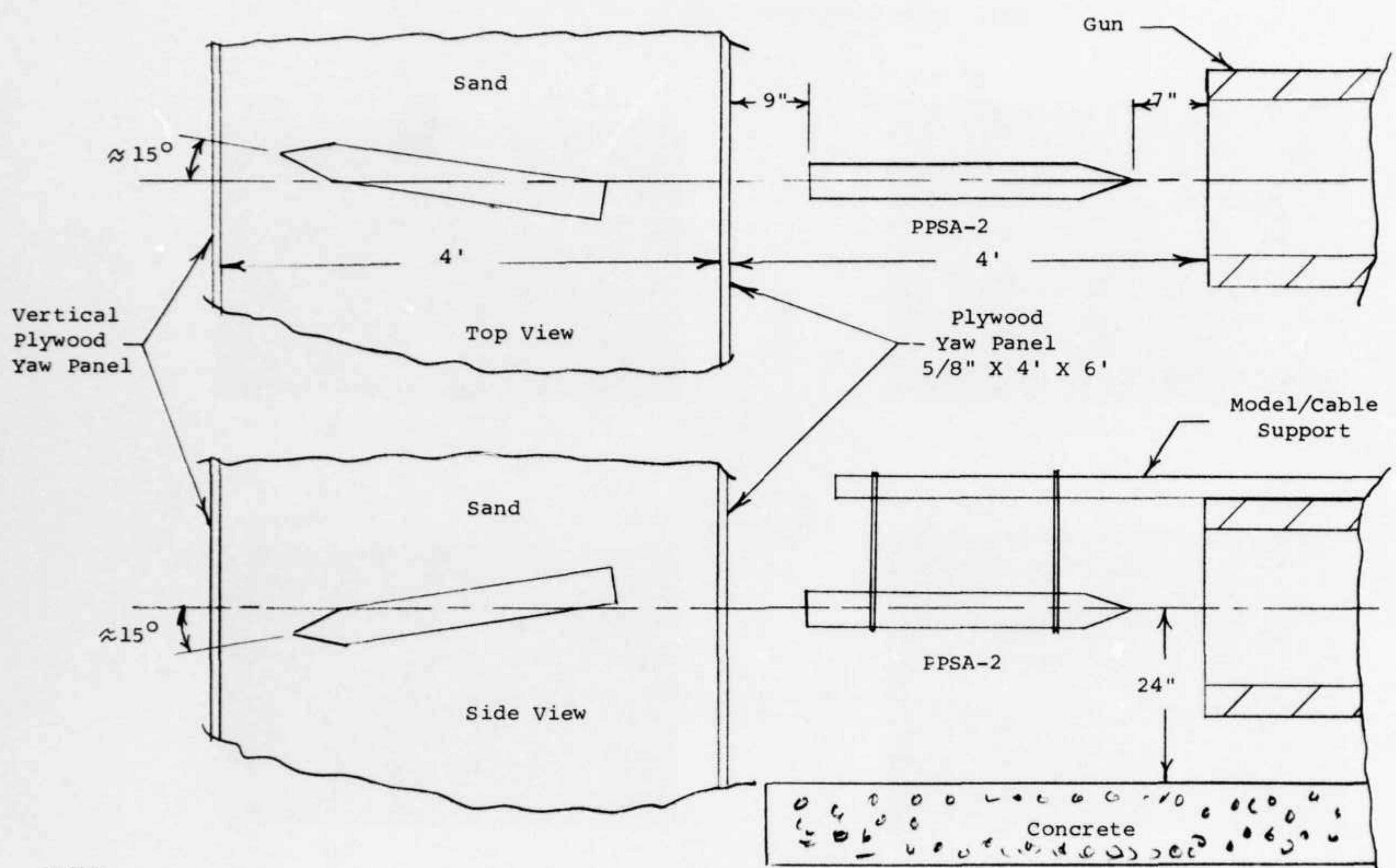


Figure 46. Model PPSA–2 post test condition and media projectile aluminum base.

Figure 47. Catcher condition after Test 2.



86-2776

Figure 48. Test 2 -- PPSA--2 model post test final position.

ALL TRACES TRIGGERED ON VELOCITY PROBE #1.

RECORD/REPRODUCE BANDWIDTH WAS D.C. to 32 KHz

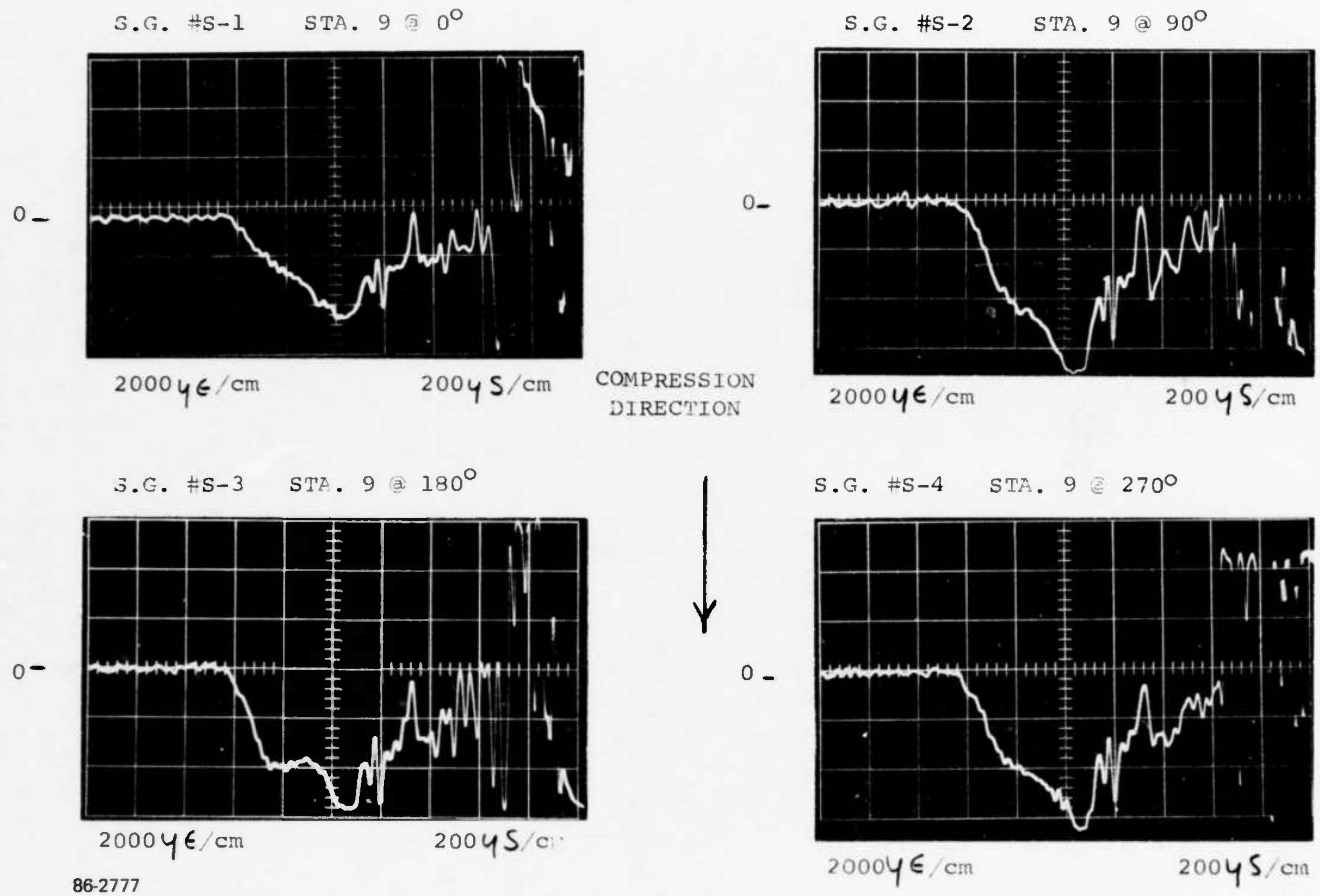
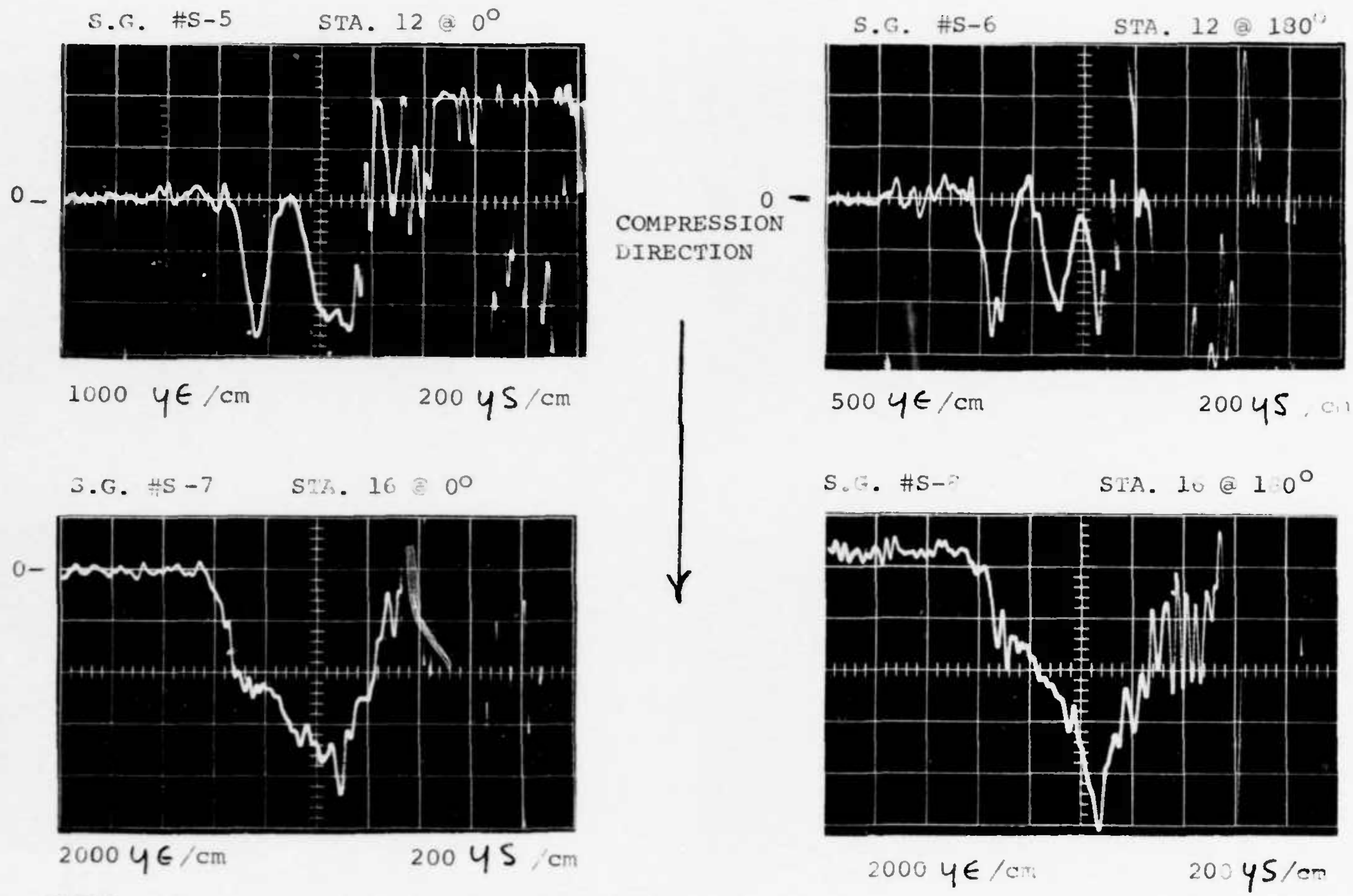


Figure 49. DNA reverse ballistic test PPSA–1 (8-26-76).

ALL TRACES TRIGGERED ON VELOCITY PROBE #1.

RECORD/REPRODUCE BANDWIDTH WAS D.C. TO 32 KHz



86-2778

Figure 50. DNA reverse ballistic test PPSA–1 (8-26-76).

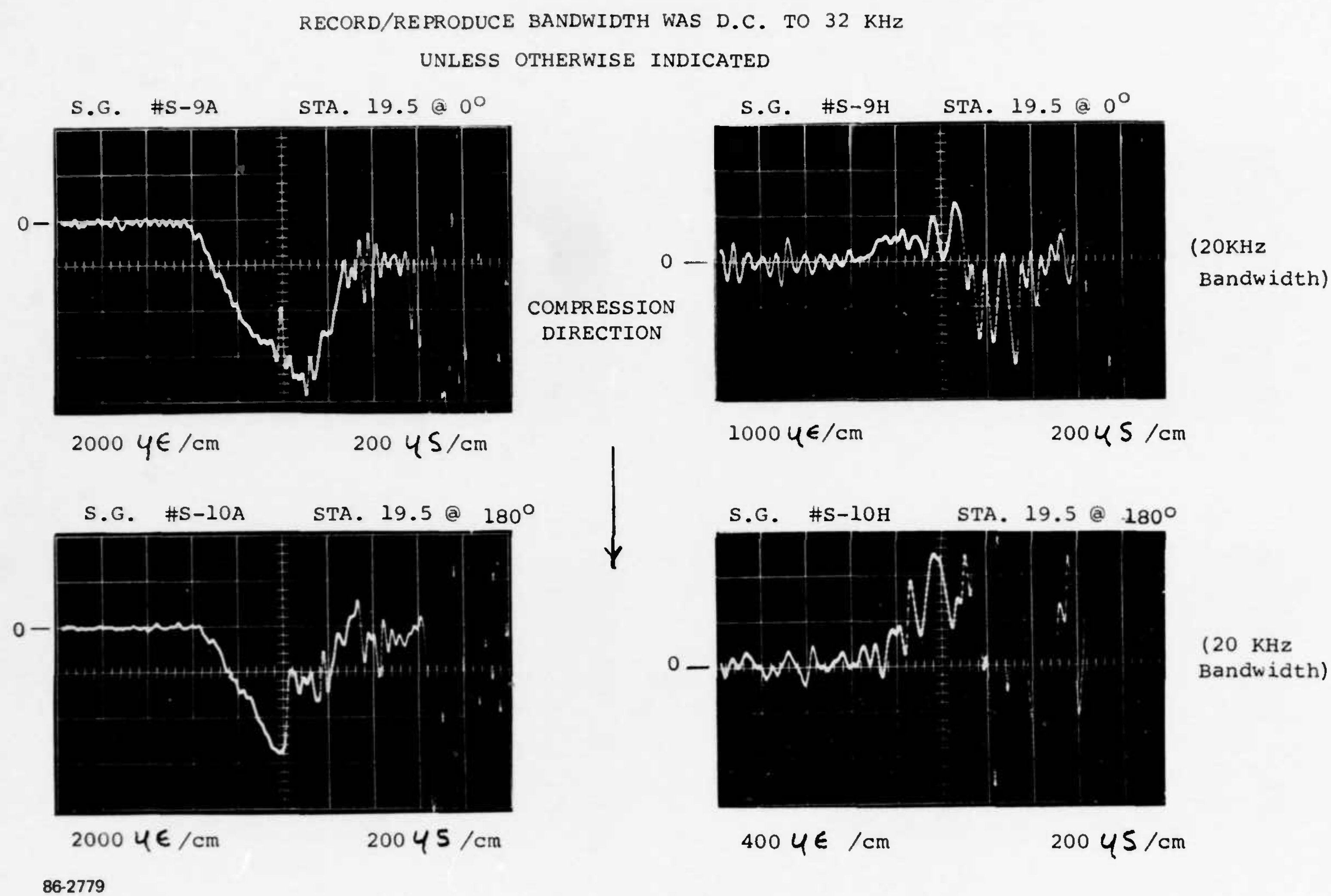


Figure 51. DNA reverse ballistic test PPSA–1 (8-26-76).

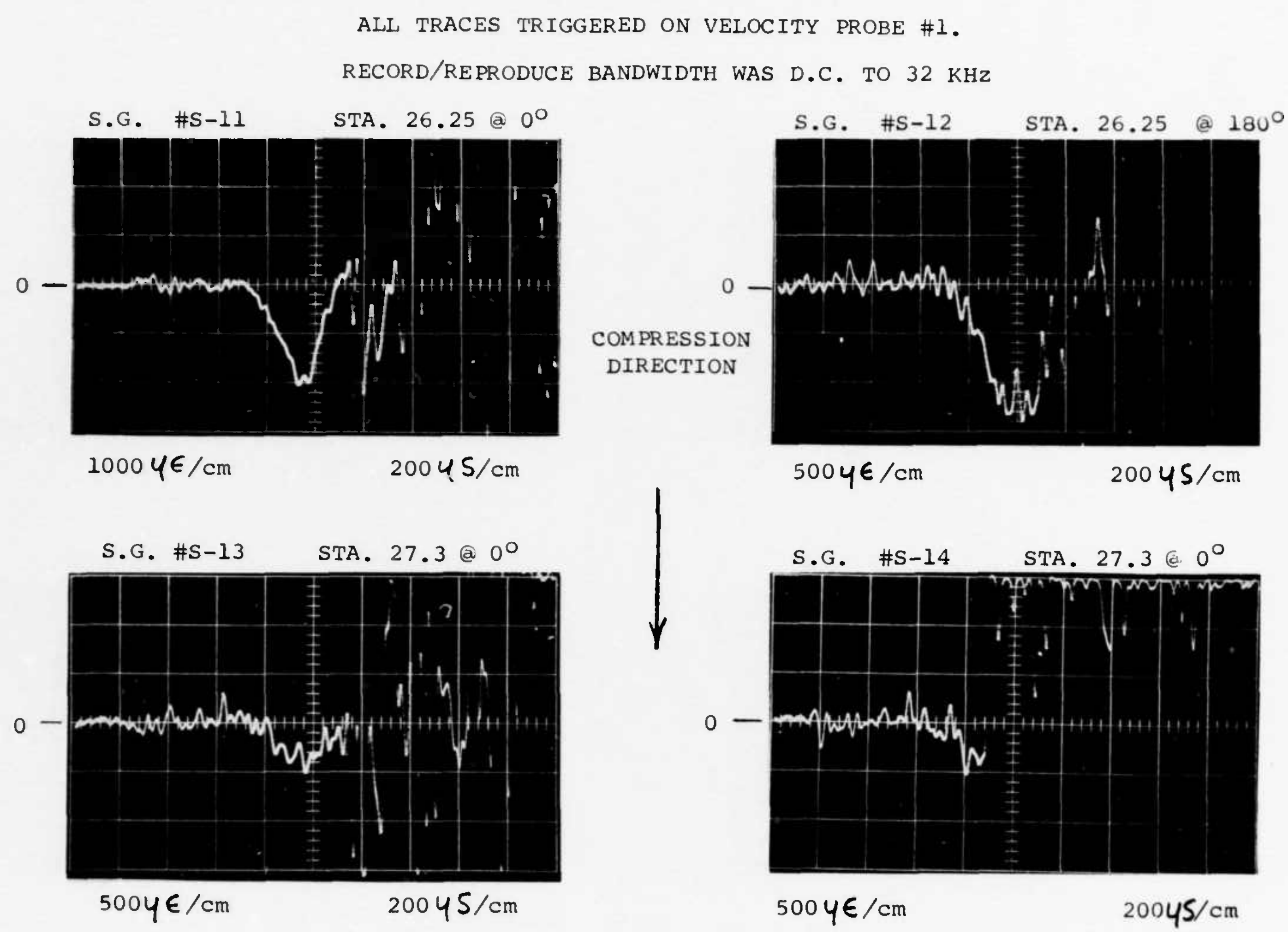


Figure 52. DNA reverse ballistic test PPSA–1 (8-26-76).

ALL TRACES TRIGGERED ON VELOCITY PROBE #1.

RECORD/REPRODUCE BANDWIDTH WAS D.C. TO 32 KHz

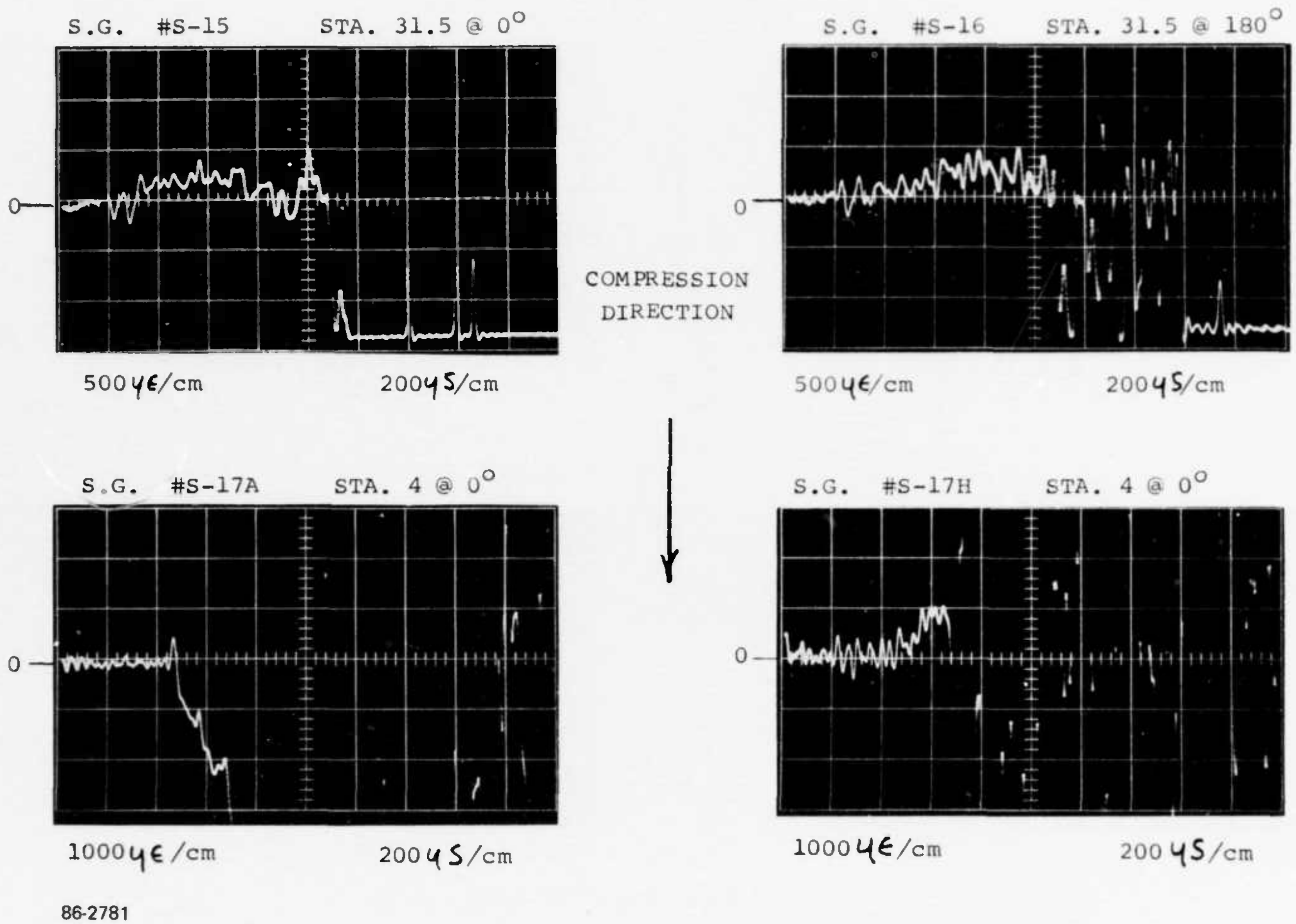
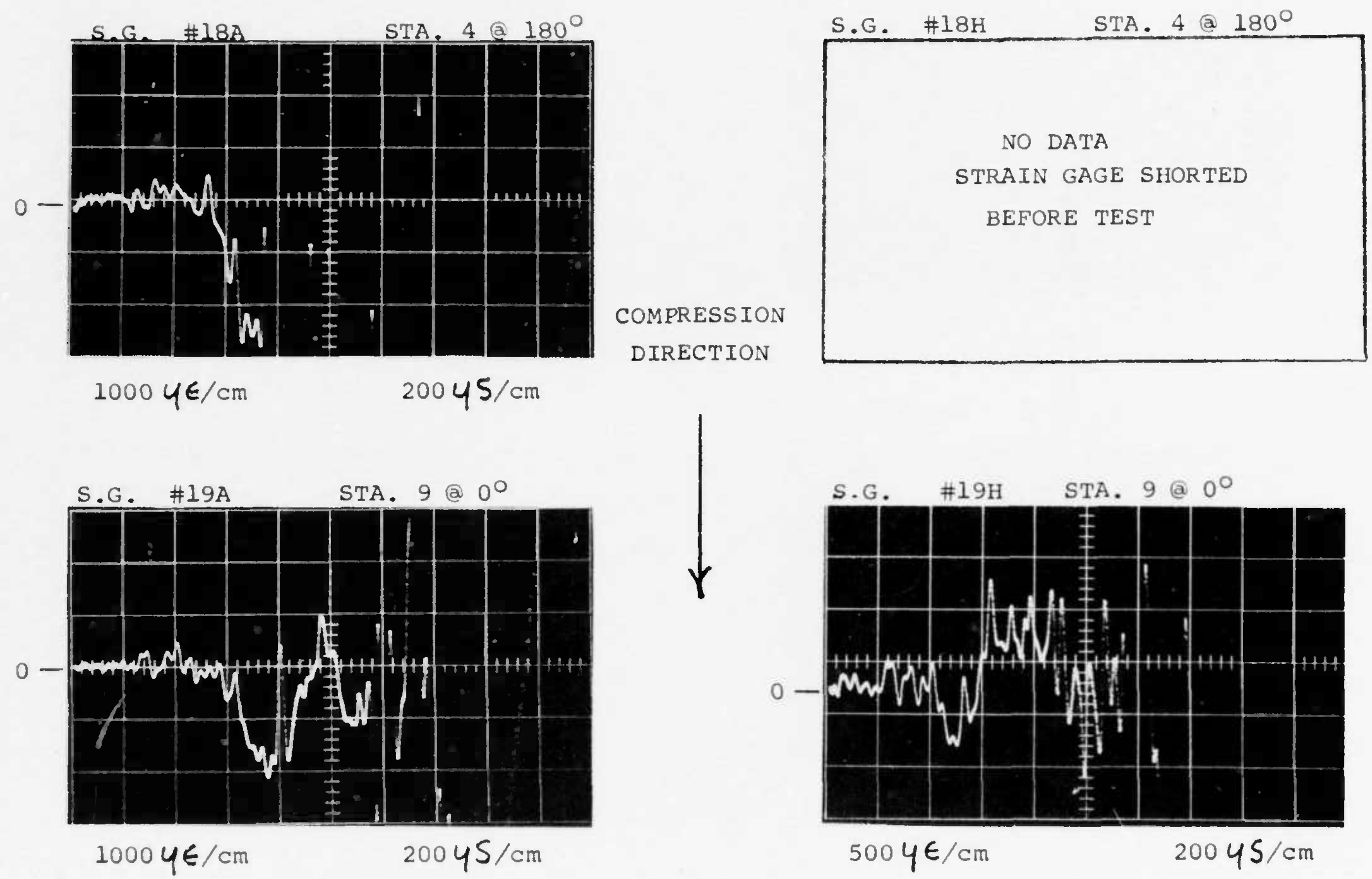


Figure 53. DNA reverse ballistic test PPSA–1 (8-26-76).

ALL TRACES TRIGGERED ON VELOCITY PROBE #1.

RECORD/REPRODUCE BANDWIDTH WAS D.C. TO 32 KHz

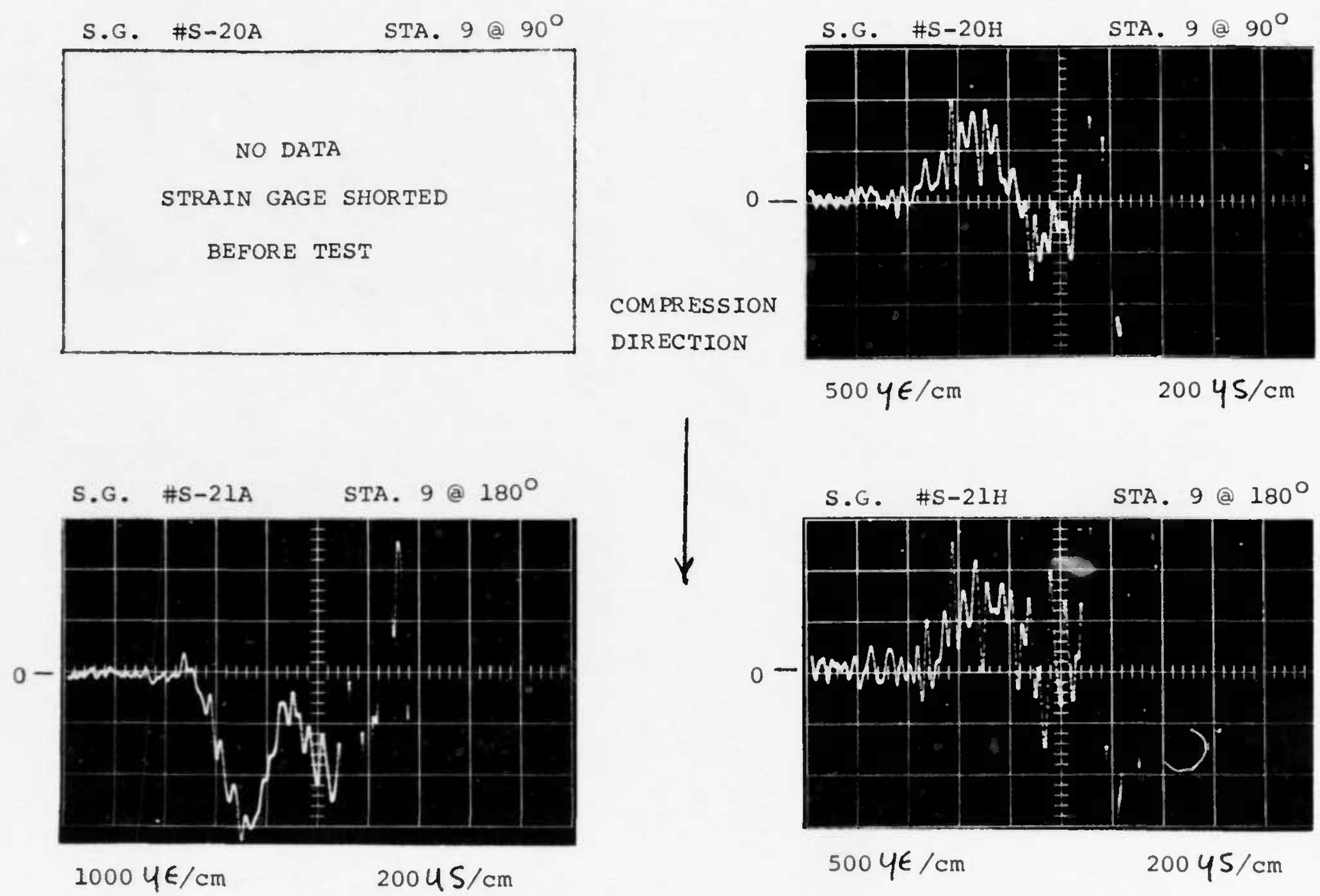


86-2782

Figure 54. DNA reverse ballistic test PPSA–1 (8-26-76).

ALL TRACES TRIGGERED ON VELOCITY PROBE #1.

RECORD/REPRODUCE BANDWIDTH WAS D.C. TO 32 KHz



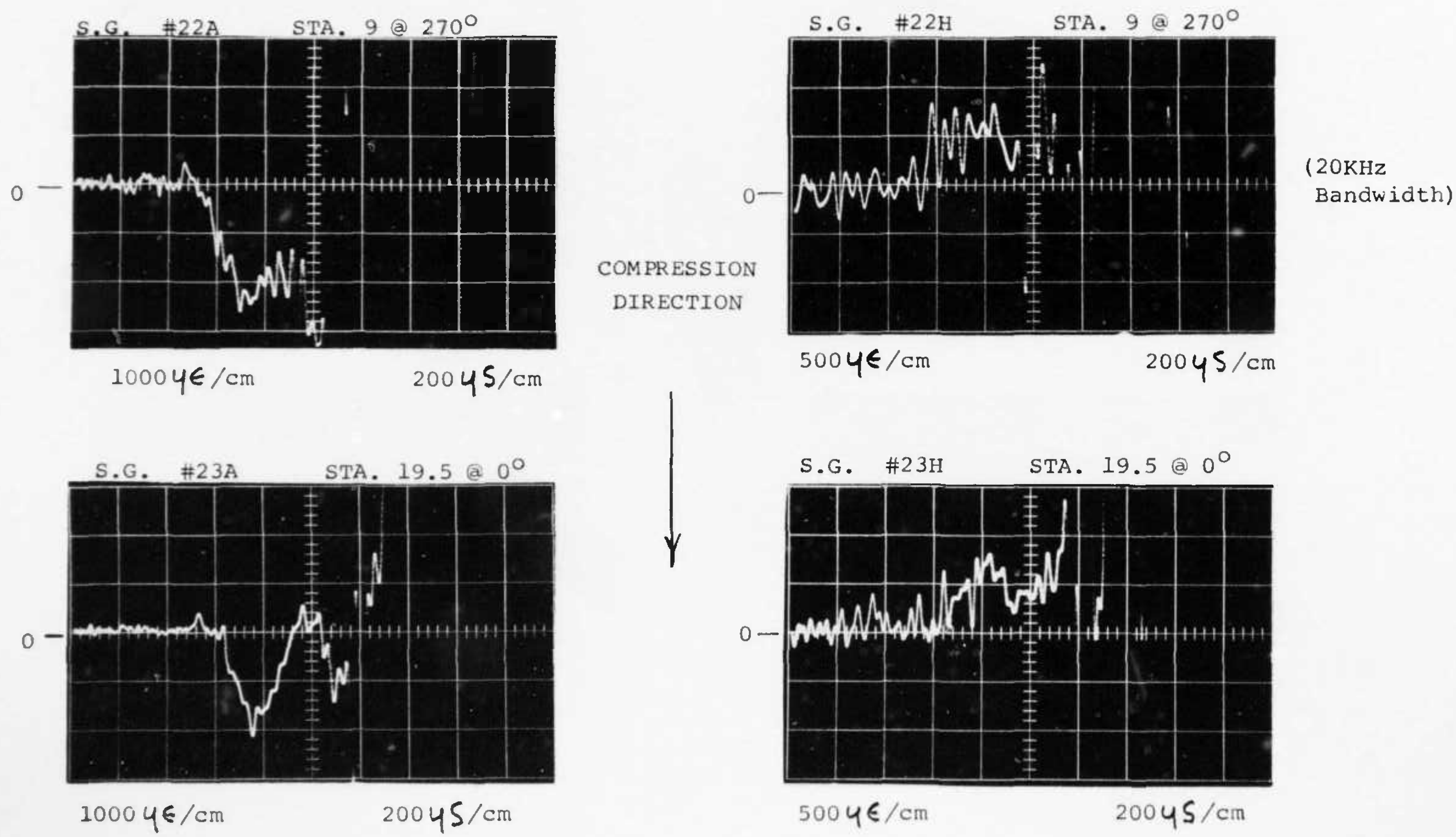
86-2783

Figure 55. DNA reverse ballistic test PPSA–1 (8-26-76).

ALL TRACES TRIGGERED ON VELOCITY PROBE #1.

RECORD/REPRODUCE BANDWIDTH WAS D.C. TO 32 KHz

UNLESS OTHERWISE INDICATED

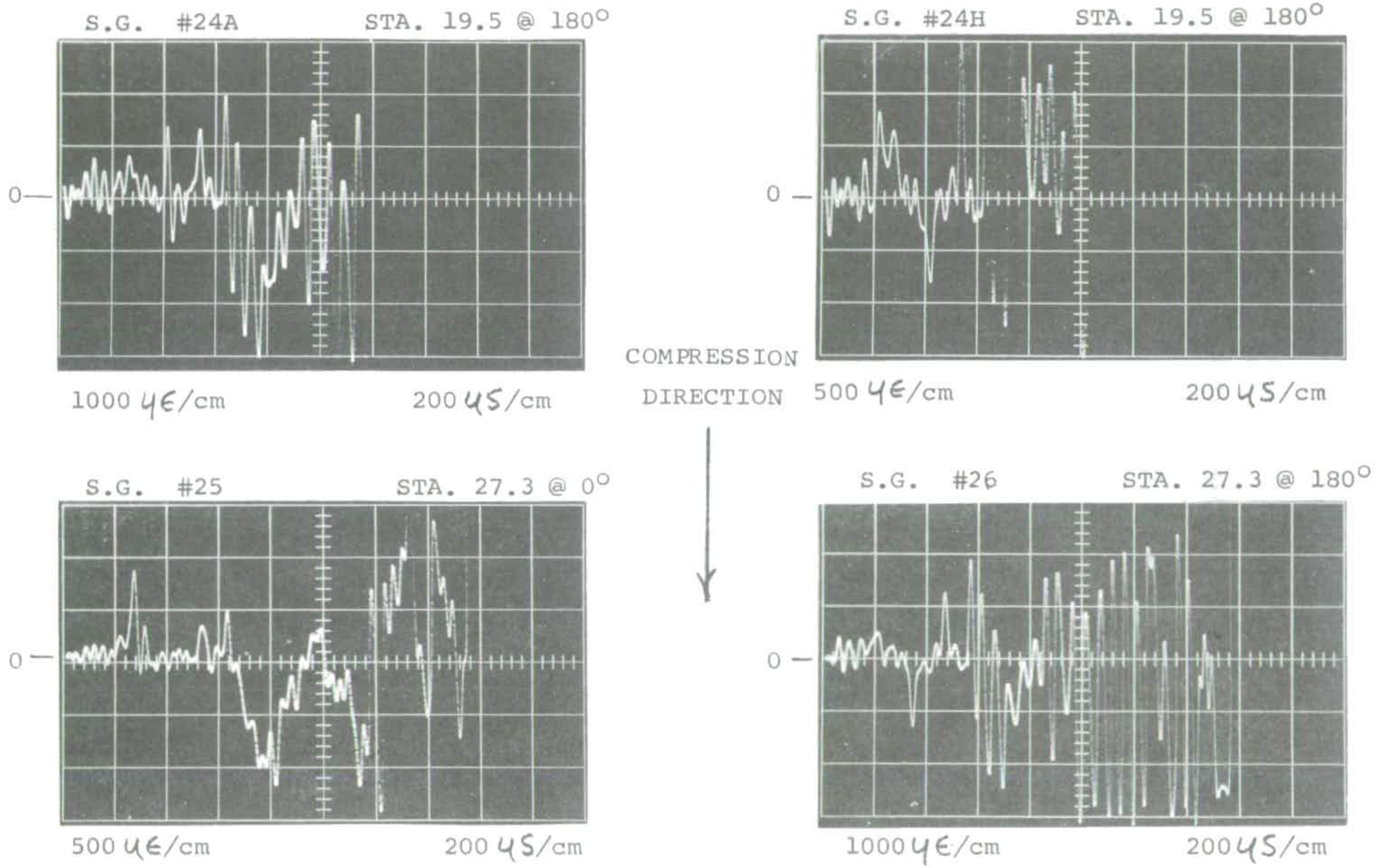


86-2784

Figure 56. DNA reverse ballistic test PPSA–1 (8-26-76).

ALL TRACES TRIGGERED ON VELOCITY PROBE #1.

RECORD/REPRODUCE BANDWIDTH WAS D.C. TO 32 KHz

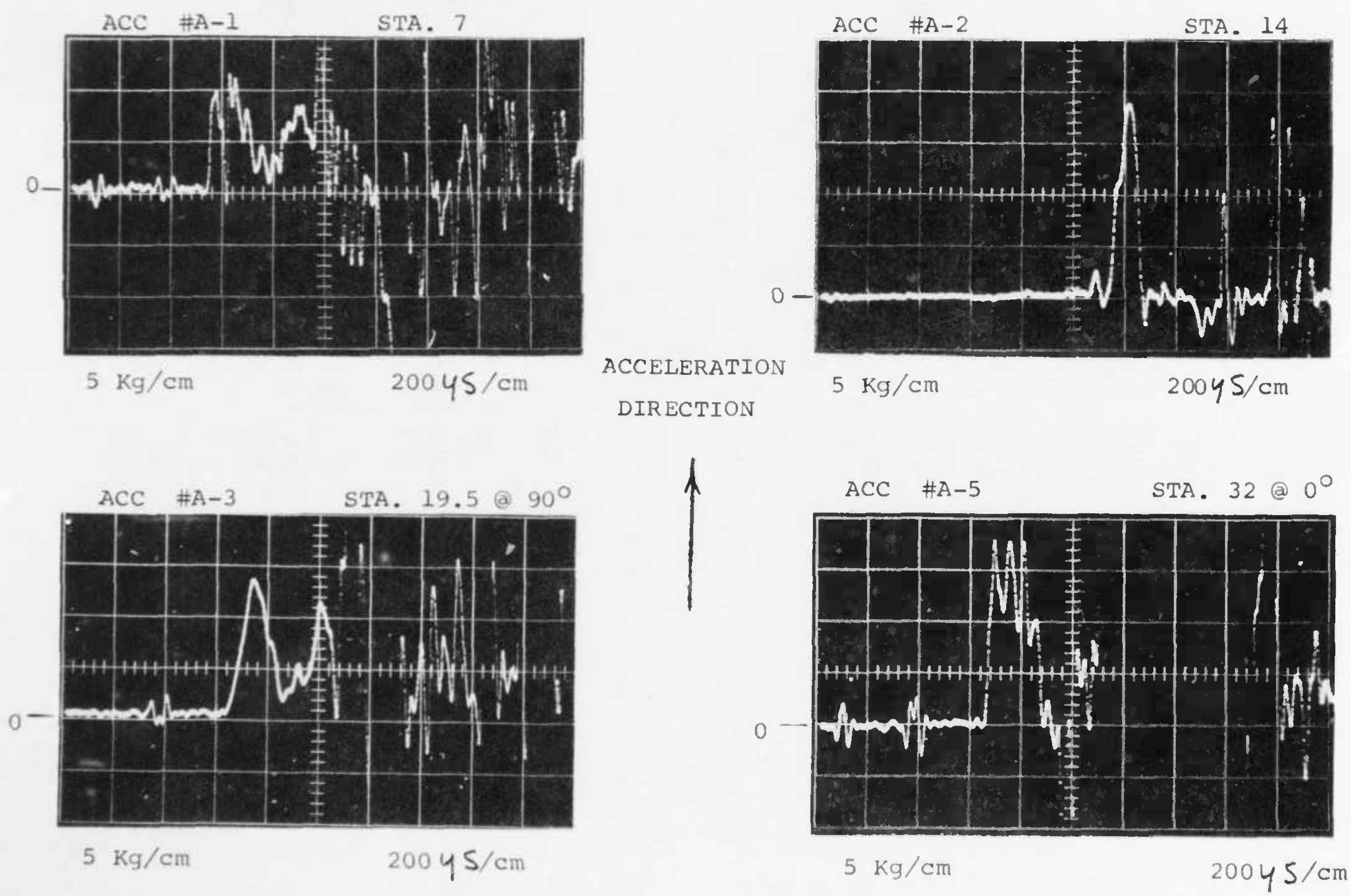


86-2785

Figure 57. DNA reverse ballistic test PPSA–1 (8-26-76).

ALL TRACES TRIGGERED ON VELOCITY PROBE #1.

RECORD/REPRODUCE BANDWIDTH WAS D.C. TO 32KHz



86-2786

Figure 58. DNA reverse ballistic test PPSA–1 (8-26-76).

ALL DATA RECORDED/REPRODUCED ON DAS-100 (D.C. - 20KHz BANDWIDTH). VELOCITY AT IMPACT = 1840 FPS.

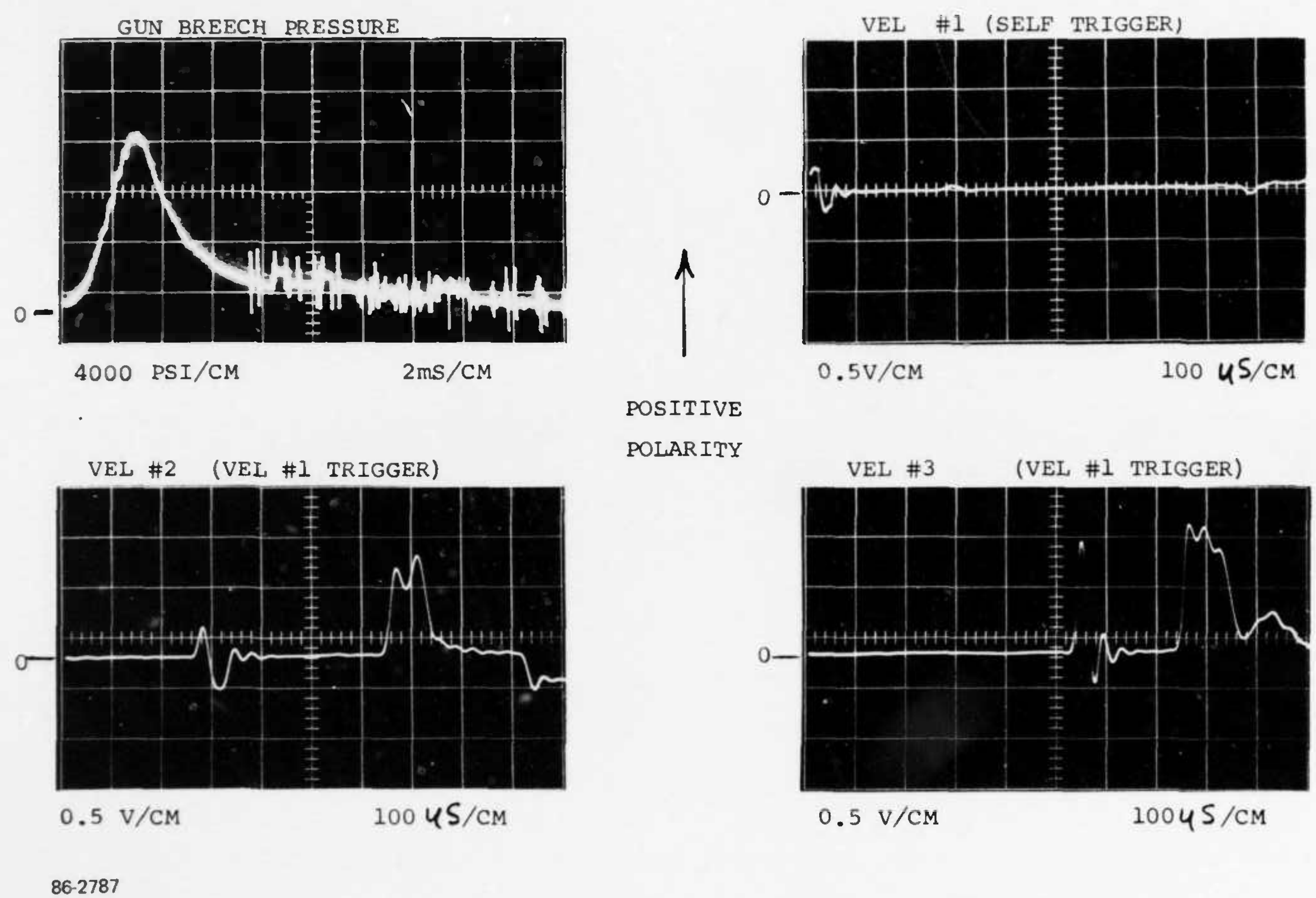


Figure 59. DNA reverse ballistic test PPSA–1 (8-26-76).

ALL TRACES TRIGGERED ON VELOCITY PROBE #1.
RECORD/REPRODUCE BANDWIDTH WAS DC TO 32 KHz

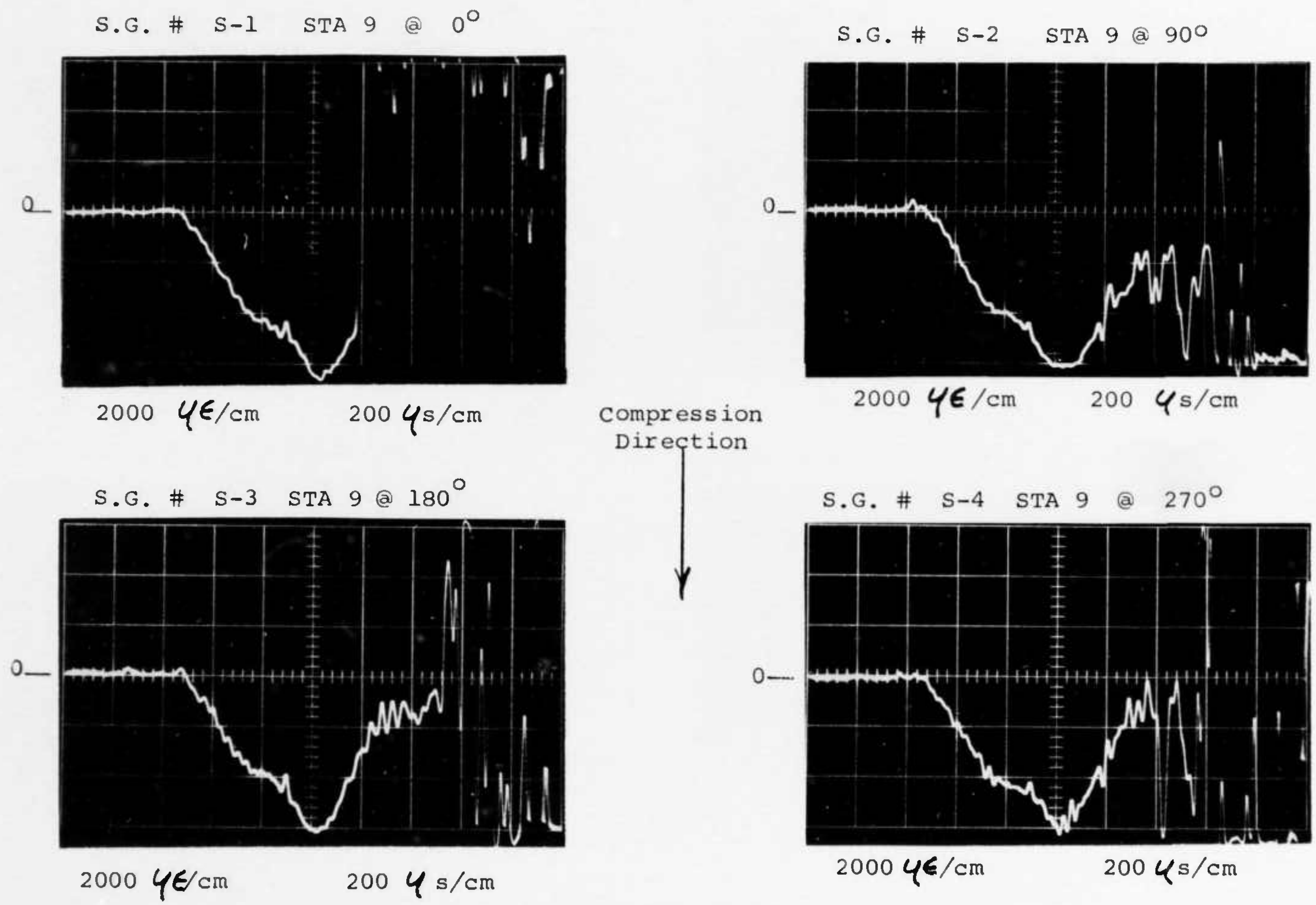


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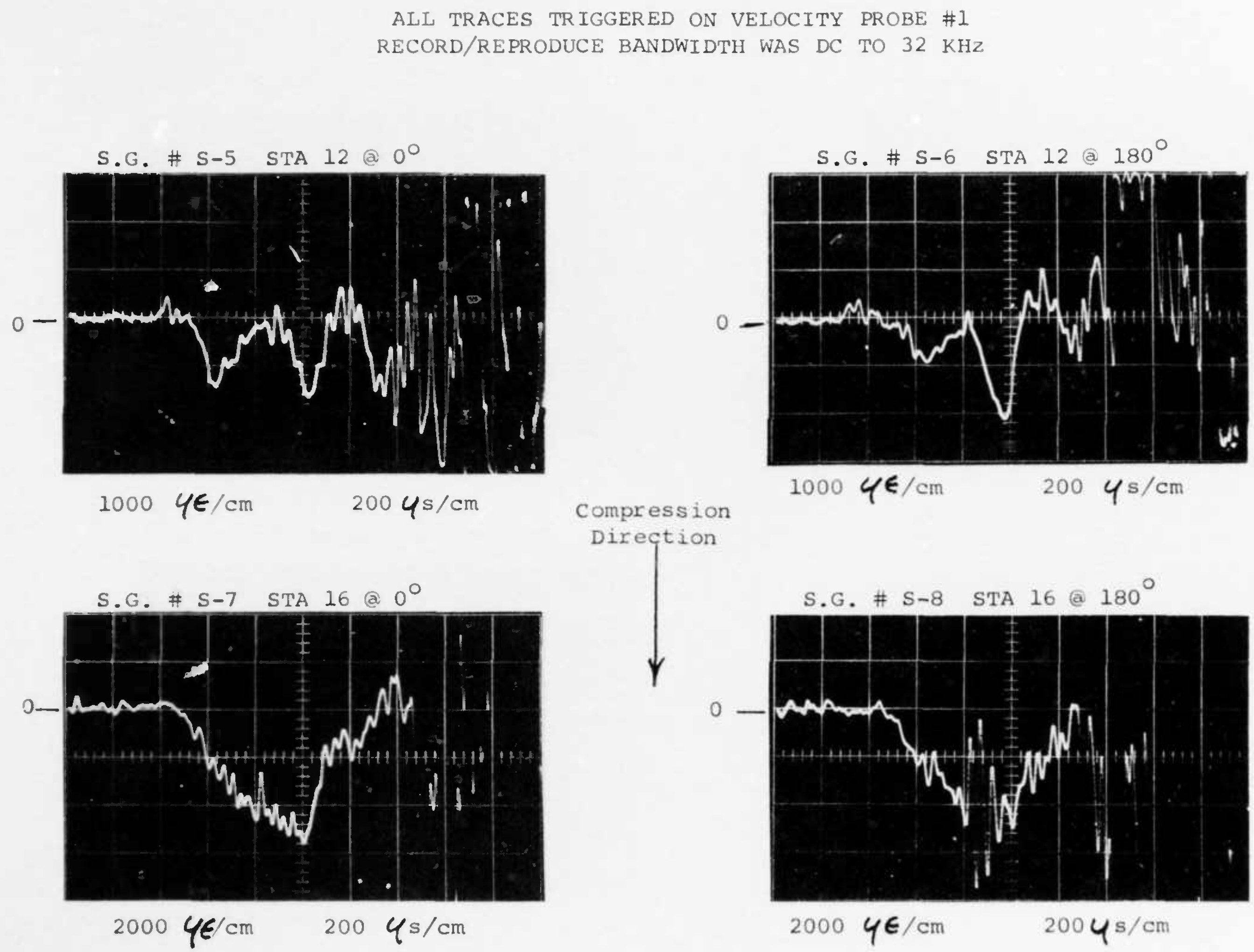
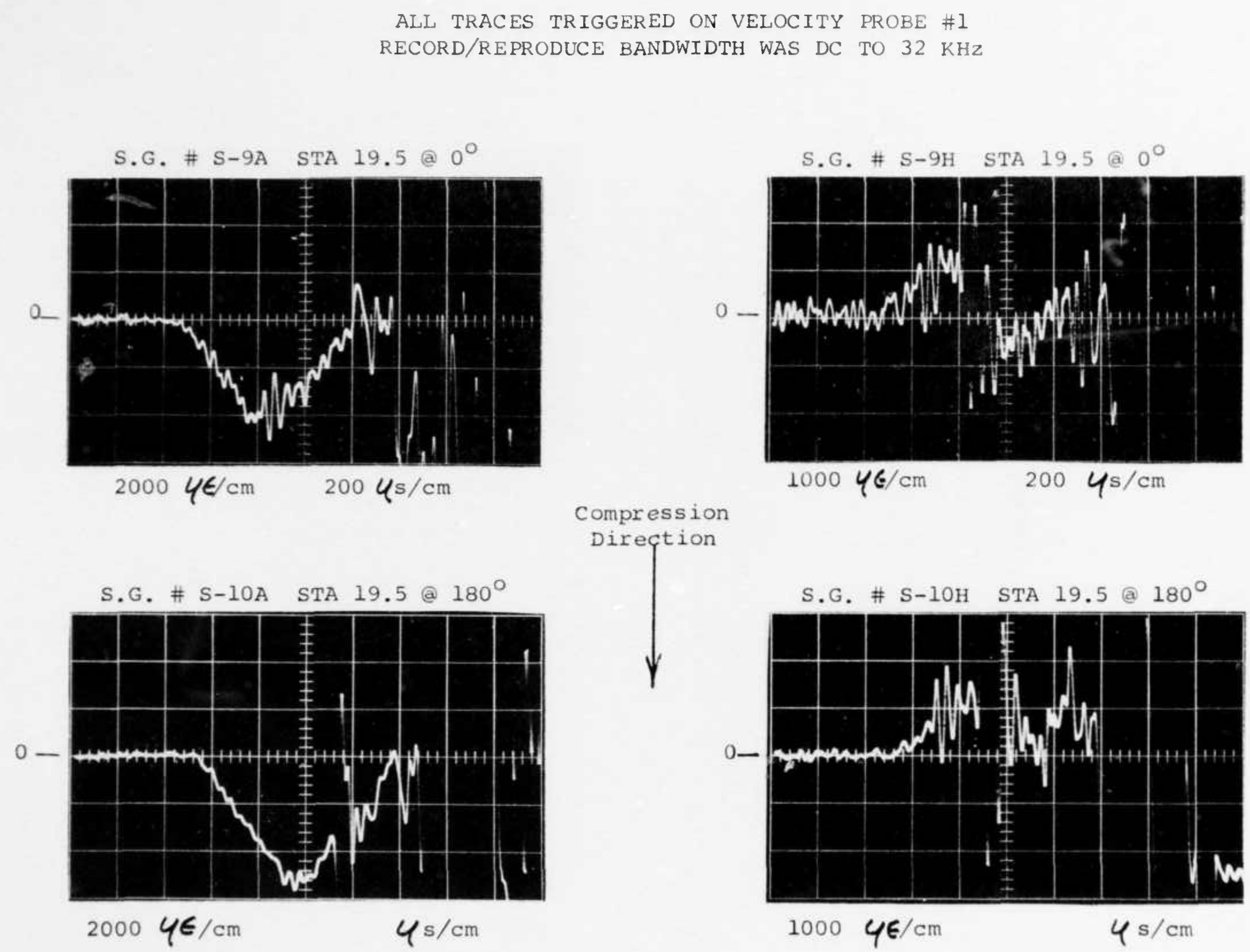
Figure 60. DNA reverse ballistic test PPSA–2 (9-9-76).



86-2789

Figure 61. DNA reverse ballistic test PPSA–2 (9-9-76).



86-2790

Figure 62. DNA reverse ballistic test PPSA–2 (9-9-76).

ALL TRACES TRIGGERED ON VELOCITY PROBE #1
RECORD/REPRODUCE BANDWIDTH WAS DC TO 32 KHz

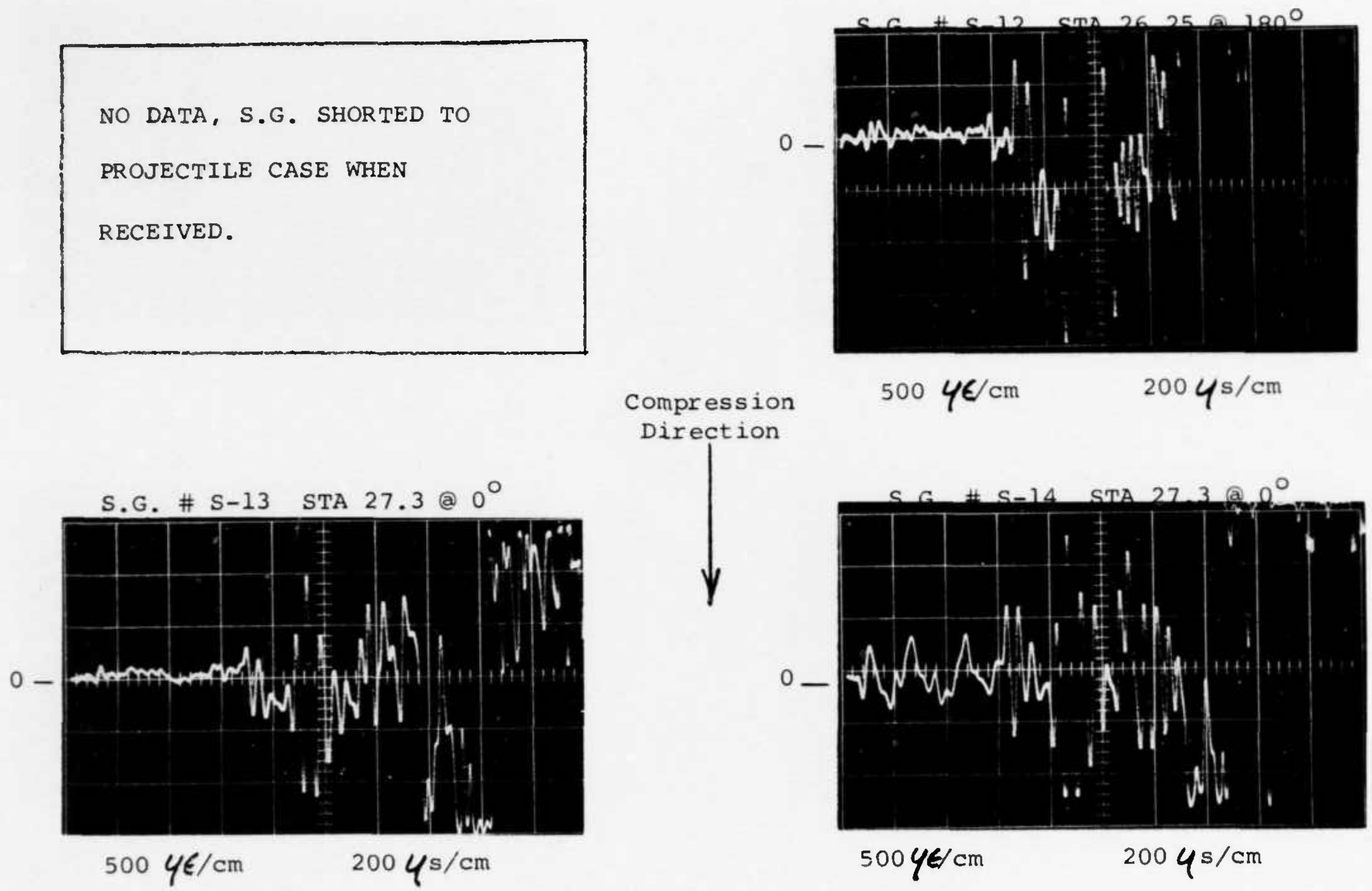


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Figure 63. DNA reverse ballistic test PPSA–2 (9-9-76).

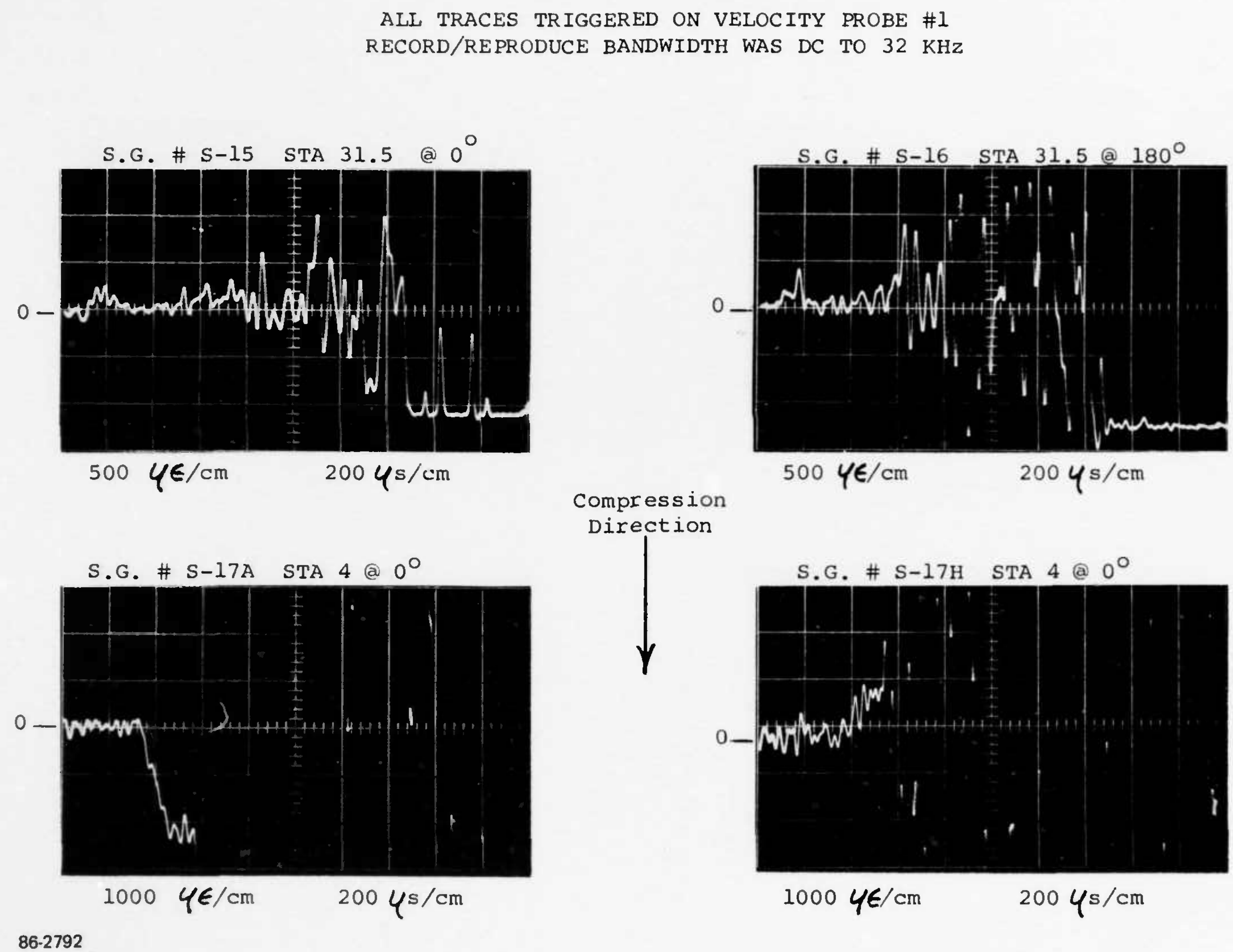


Figure 64. DNA reverse ballistic test PPSA–2 (9-9-76).

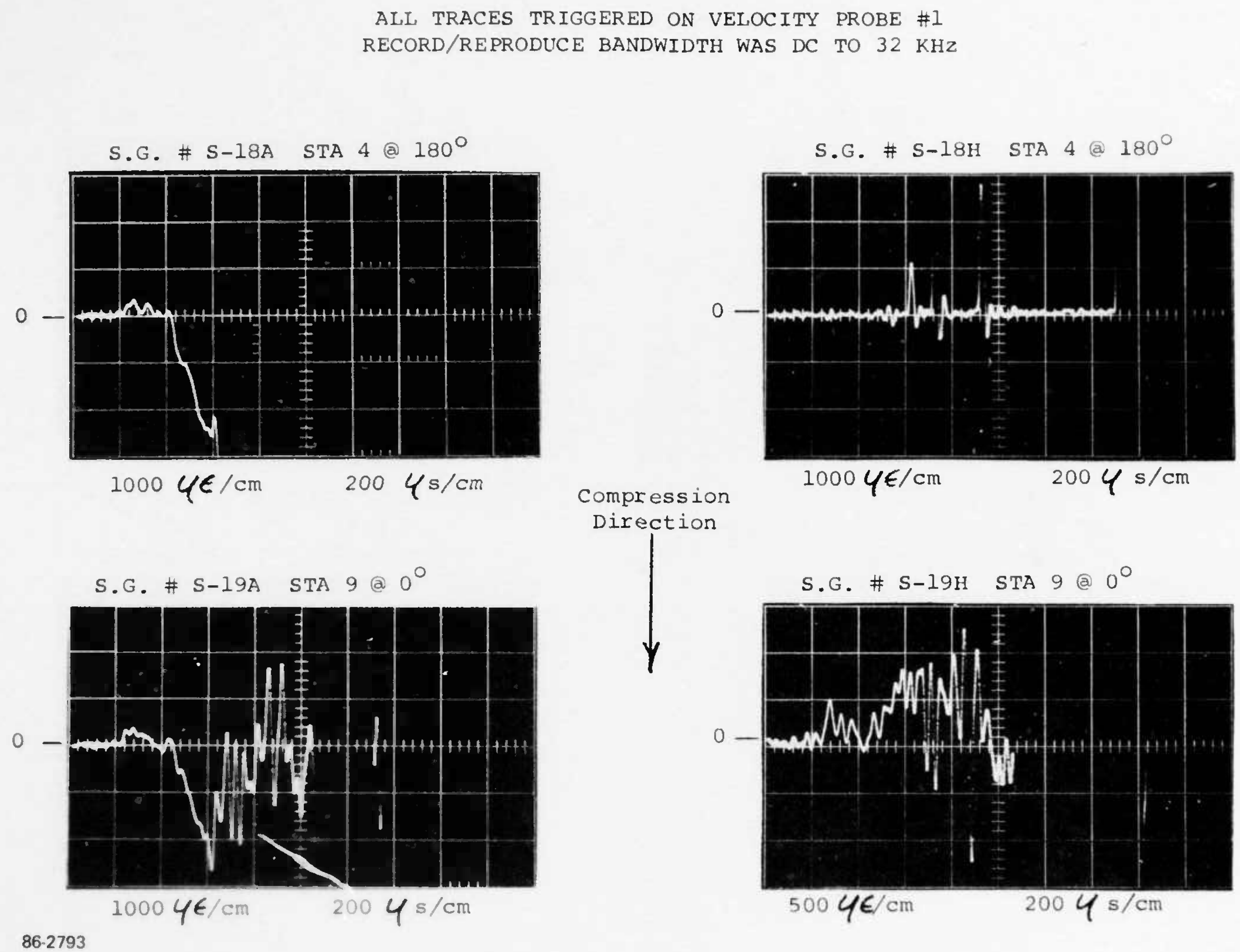


Figure 65. DNA reverse ballistic test PPSA–2 (9-9-76).

ALL TRACES TRIGGERED ON VELOCITY PROBE #1
RECORD/REPRODUCE BANDWIDTH WAS DC TO 32KHz

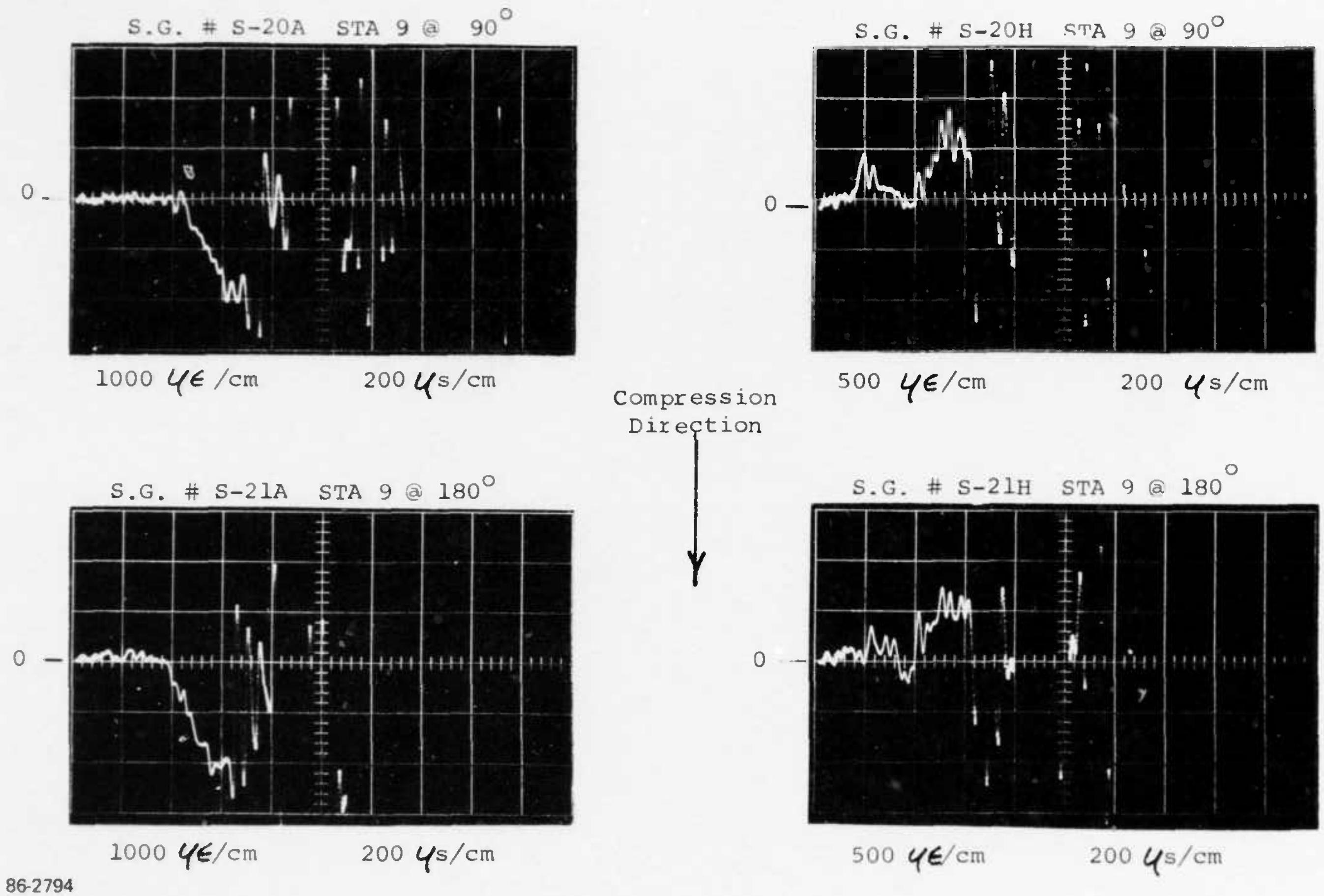
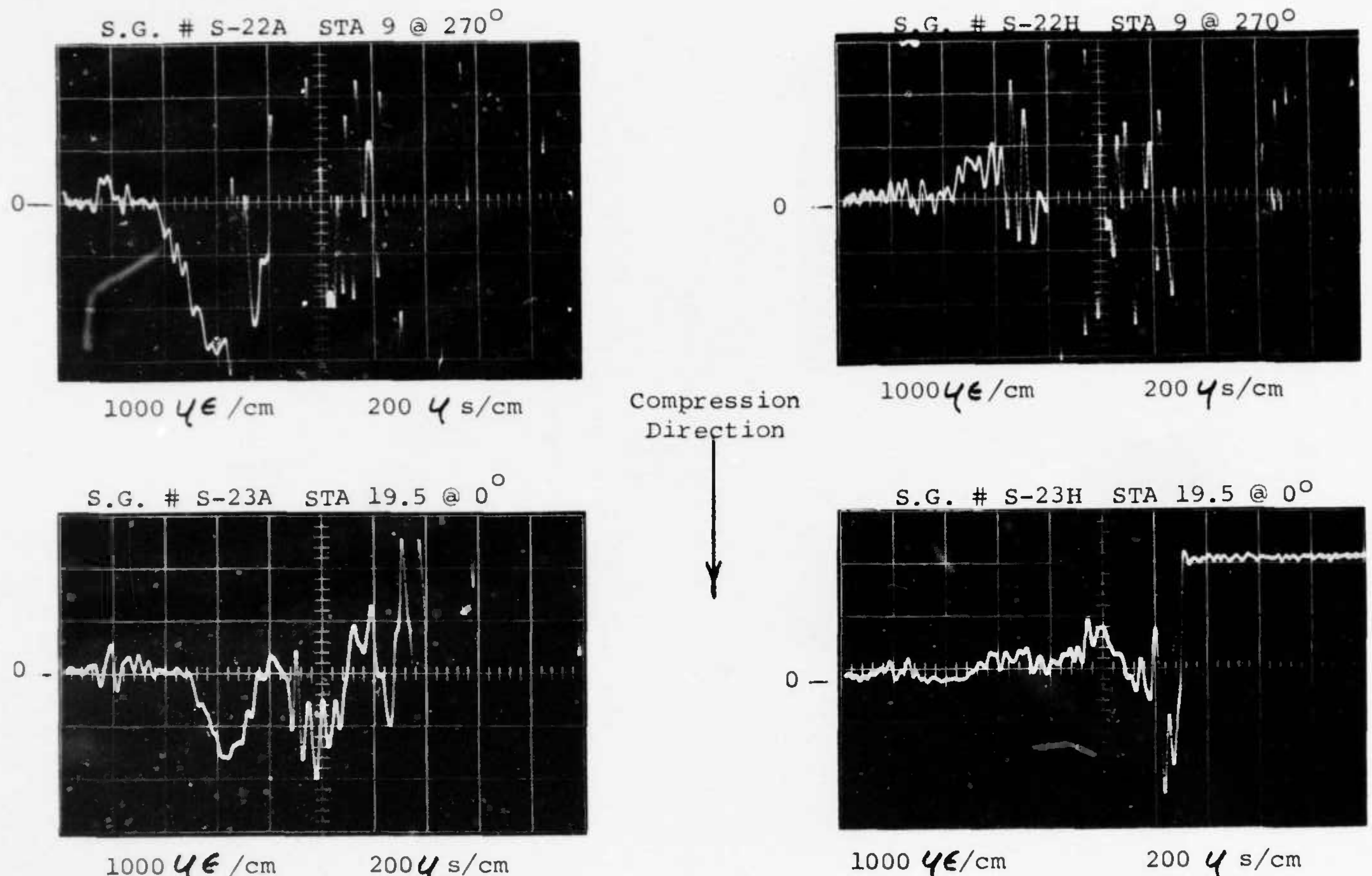


Figure 66. DNA reverse ballistic test PPSA–2 (9-9-76).

ALL TRACES TRIGGERED ON VELOCITY PROBE #1
RECORD/REPRODUCE BANDWIDTH WAS DC TO 32 KHz



86-2795

Figure 67. DNA reverse ballistic test PPSA–2 (9-9-76).

ALL TRACES TRIGGERED ON VELOCITY PROBE #1
RECORD/REPRODUCE BANDWIDTH WAS DC TO 32 KHz

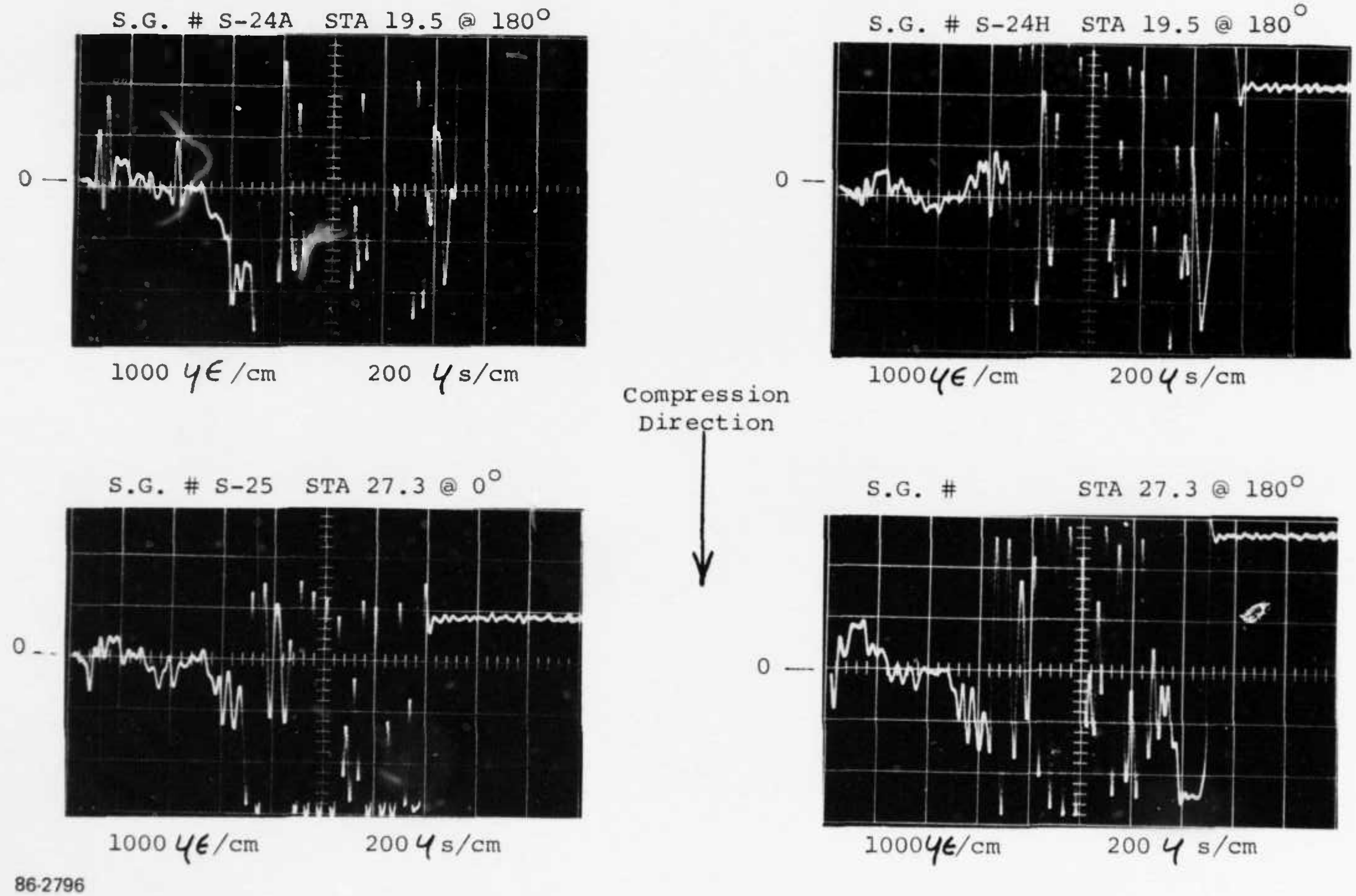


Figure 68. DNA reverse ballistic test PPSA–2 (9-9-76).

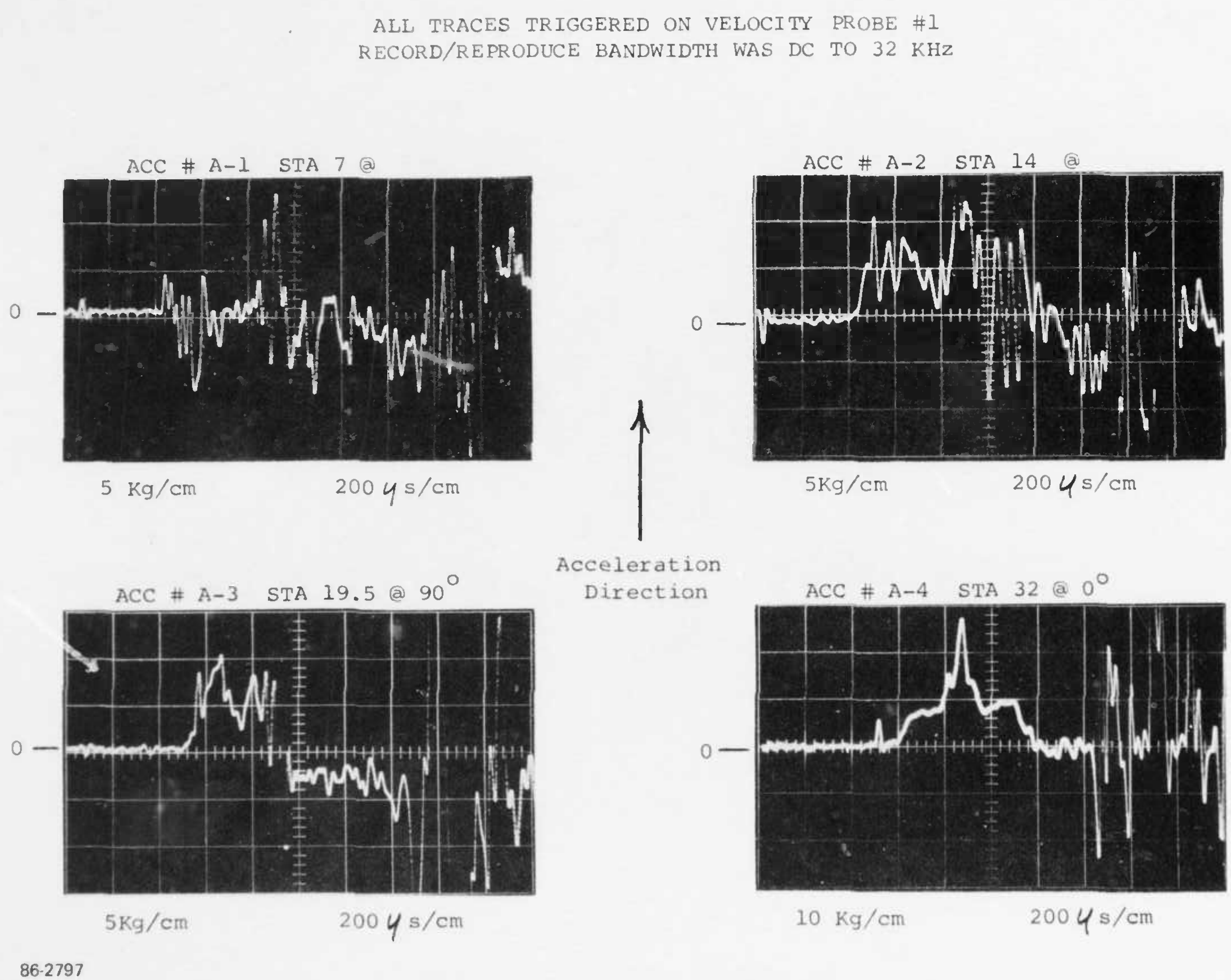
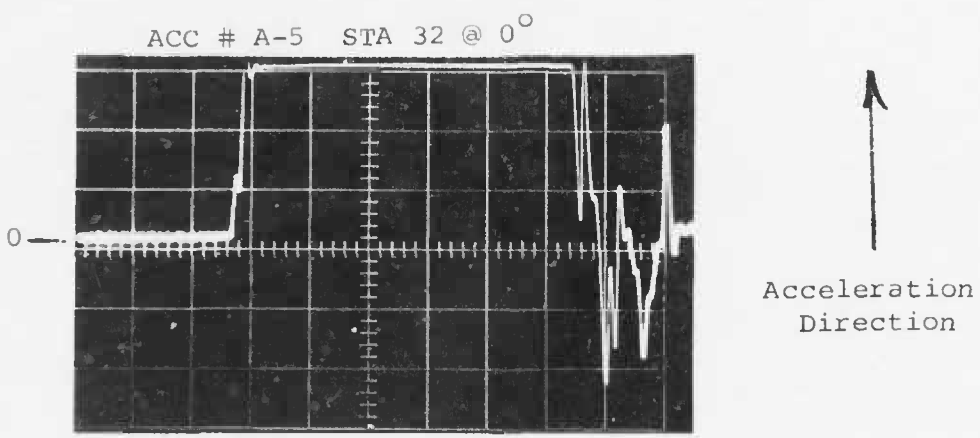


Figure 69. DNA reverse ballistic test PPSA–2 (9-9-76).

TRACE TRIGGERED ON VELOCITY PROBE #1
RECORD/REPRODUCE BANDWIDTH WAS DC-32KHz



86-2798

Figure 70. DNA reverse ballistic test PPSA–2 (9-9-76).

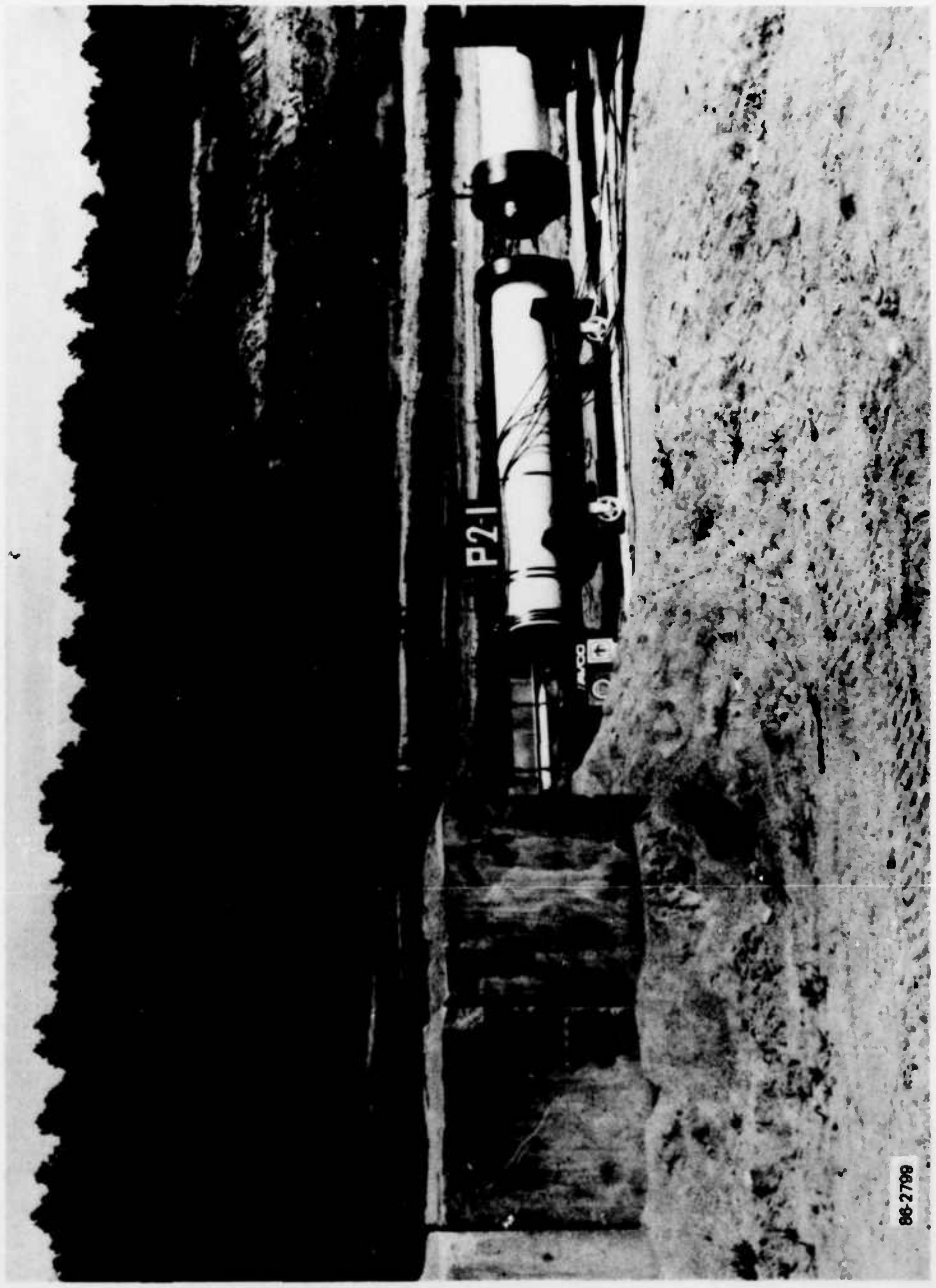


Figure 71. Test 1 – PPSA–1 model and reverse ballistic gun setup.

Figure 72. Test 1 – model PPSA–1 test setup.

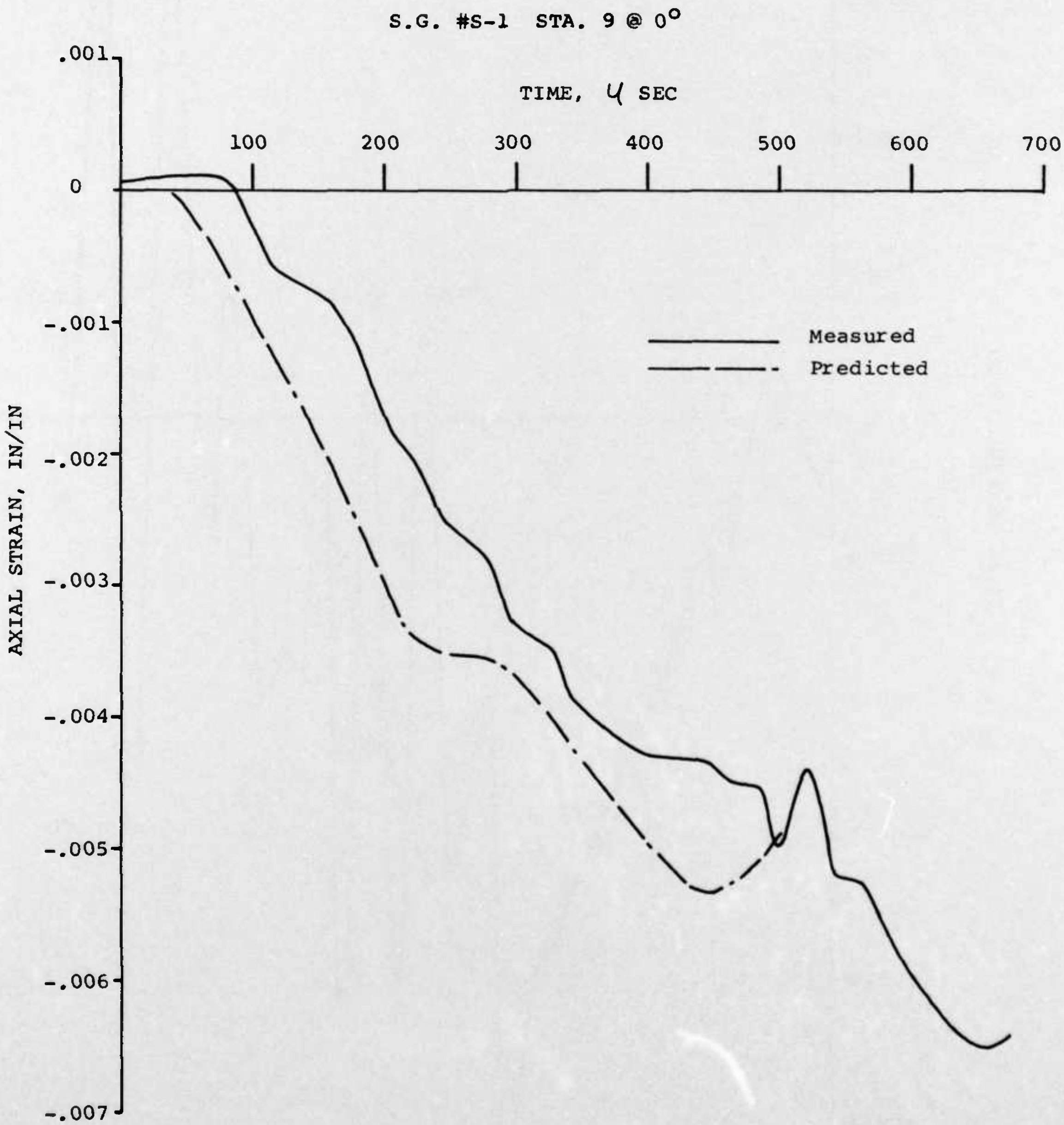
damaged approximately 0.2 millisecond after impact. Second, the media only acts in a semi-infinite nature for approximately 0.5 millisecond, at which time the media projectile aluminum base plate impacts the EP nose. Internal gages in general do not fail until the leads coming out of the aft end of the model are damaged by debris about 1 millisecond after impact.

Data was recovered by playback onto an oscilloscope equipped with a Polaroid camera. The scope was triggered by the first velocity probe output. Time of impact can be related to each data trace by using the corrections listed in the last two columns of Table 2. Times vary for the same test due to static skew and gap scatter variations in the tape transport head geometry.

Values of peak axial strain, peak hoop strain and peak acceleration for the two tests and pretest predictions are listed in Tables 5, 6, and 7. For cases where there was more than one strain gage at a given station, peak strain was averaged. Peak predicted strain is the average of all credible pretest predictions.

Table 5 (axial strain) shows that there is good correlation of peak values from test-to-test and from test-to-prediction, particularly for gages on the EP shell. Correlation of hoop strain levels (Table 6) was also reasonable although data was more difficult to interpret due to lower signal and higher relative noise levels. Correlation of accelerometer peak levels (Table 7) is also reasonable. Correlations of strain and accelerometer time histories with predictions for a few selected typical cases are shown in Figures 73, 74 and 75. In general, such correlation was good for approximately 0.3 to 0.6 millisecond after impact.

In summary, test performance, quality of data, correlation of data, etc. was excellent. Return of strain gage data was 95% for both tests which is a very high return rate for tests of this nature. Return of accelerometer data was 60% with reasonable data being obtained from all five locations on at least one test.



86-2801

Figure 73. DNA reverse ballistic test PPSA–2 (9-9-76).

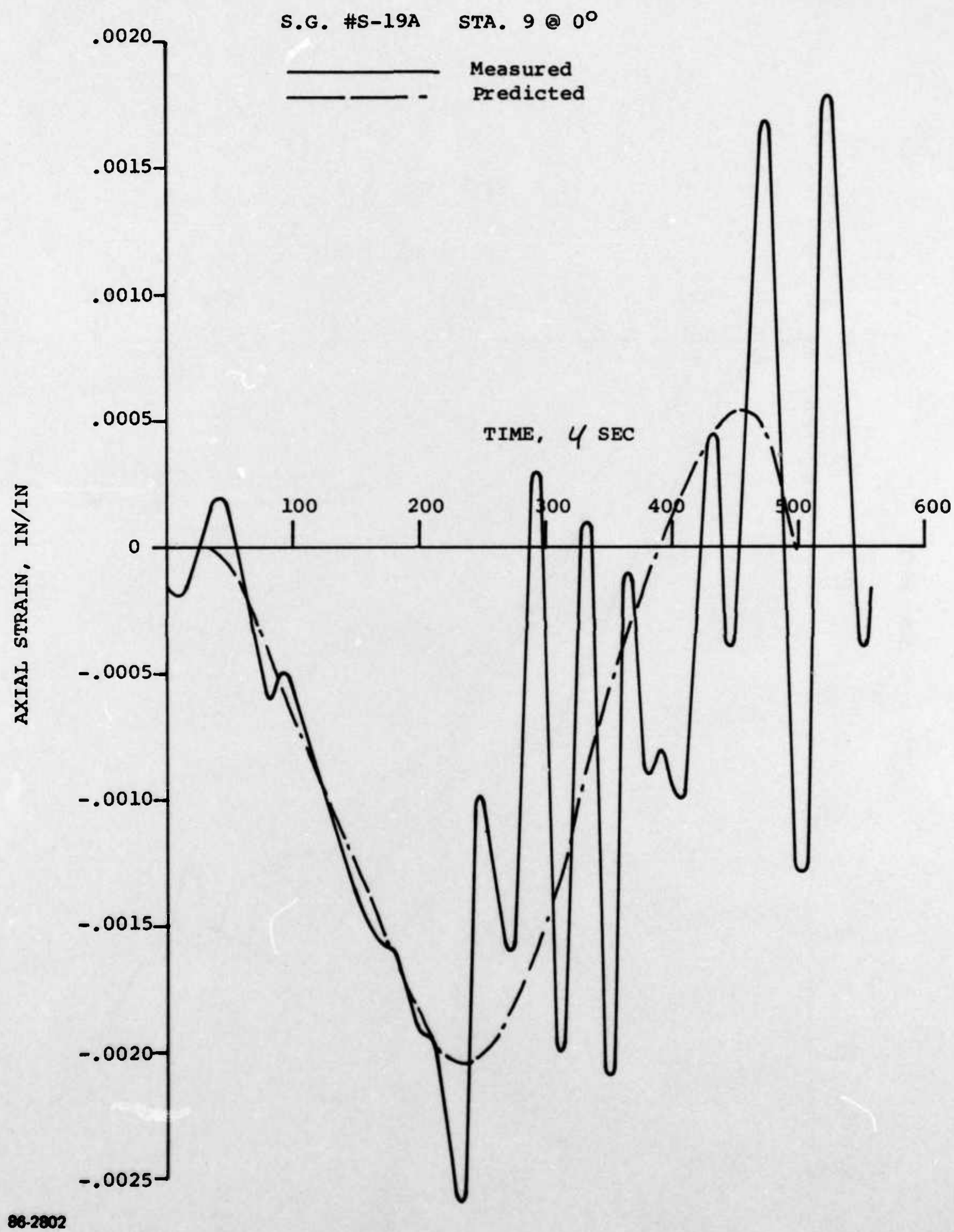
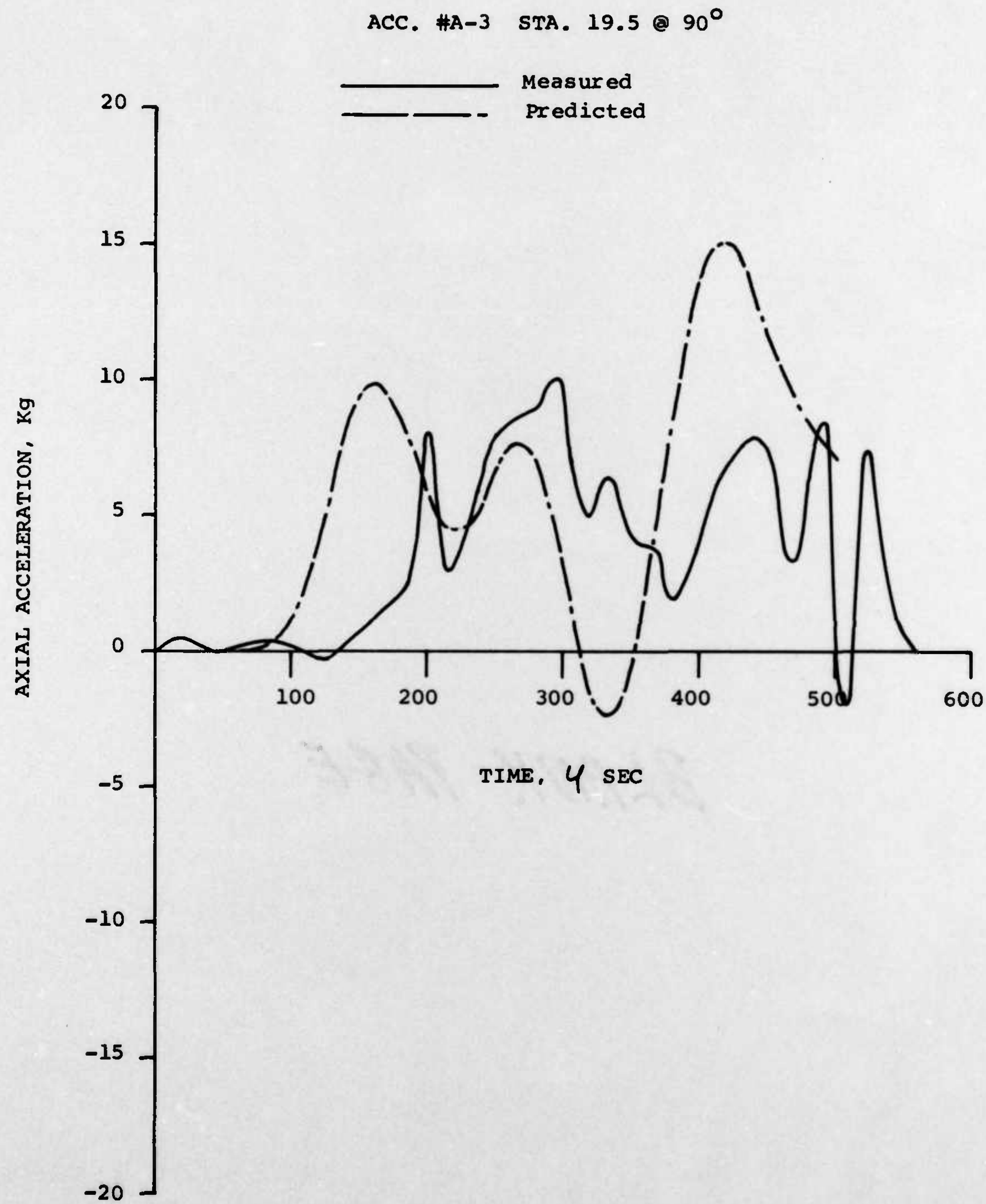


Figure 74. DNA reverse ballistic test PPSA–2 (9-9-76).



86-2803

Figure 75. DNA reverse ballistic test PPSA–2 (9-9-76).

4.0 SUMMARY

The results of the demonstration tests provided confidence that all P-2 test objectives would be met. Media integrity and velocity, improved film coverage and projectile recovery were all successfully demonstrated.

As a result of the demonstration test approach together with careful planning, the P-2 RBT's were highly successful. Desired test velocities, in the 1800 ft/s range, were achieved. Excellent film coverage was obtained which permitted detailed determination of both the EP and media motion with time during the critical period at and just after impact. This data is presented in Figures 38, 39, 42 and 43. The momentum exchange can be calculated by figuring the EP velocity from the slopes of the appropriate curves (Figures 39 or 43). From Figure 39 the EP velocity is calculated at 104 ft/s. Because the EP weighs 47 pounds the momentum of the EP after impact for P-2 Test 1 equaled 152 pound-seconds. The momentum of the media projectile is 9575 pound-seconds at a 1927 ft/s velocity. Therefore the momentum exchange was only 1.6 percent of the momentum available. This verifies the velocity of the RBT approach for the P-2 application.

The amount and quality of the data acquired on both tests was remarkable. Table 3 summarizes the data acquisition and provides a gross comparison of the measured and predicted data. More detailed comparisons of measured and predicted strains and accelerations are presented in Tables 5, 6 and 7. The test data compared well both with pretest predictions and from test-to-test as seen in the tables. The high retrieval rate, quality and repeatability of the test data for high velocity impact conditions is unprecedented and serves to substantiate the value of the RBT technique. The excellent comparison between the measured data and the pretest predictions serves to validate existing analytical techniques.

The comparisons of data presented in Tables 3, 5, 6 and 7 or by observation of the data in Figures 49 to 70 provides a general comparison at best. The pretest predictions are presented in Reference 2. The remarkable similarity of test data curve shapes from test-to-test and with pretest predictions verify both the test and predictive techniques employed.

The recovery of both P-2 projectiles intact at the conclusion of testing permitted these items to be returned to Sandia for disassembly and detailed examination.

5.0 REFERENCES

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2. Letter from P. Hadala, Waterways Experiment Station, Corps of Engineers; Vicksburg, Mississippi, "Comparison of Pretest Predicted Time Histories from Half-Scale Earth Penetrator Dynamic Structural Response Analyses", dated 16 June 1976.

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